Students at the Speedway Family Activity Workbook

Photo courtesy of VPS Motorimages

Fun & Family-Focused Math & Science for Middle & High School Learners

Having both speed and direction gets you wherever you want to go, fast! You can go further and faster by learning that math and science are fun as well as fundamental to most of your future endeavors.

Did you know that motorsports like NASCAR is the only sport won or lost through the real-time application of math and science; the same math and science you're learning in school?

We wish you and your family hours of enjoyable learning together with the Bank of America Family Activity Workbook developed by the engineers & educators of Ten80 Education.

Bank of America 500

ten80 Education

www.FastTrackRC.com
www.Ten80Education.com

Bank of America Family Activity Workbook

Measurement & Units · Forces & Motion · Work & Machines

Table of Contents

The subscript K (example^K) indicates there is an entry in the Key at the end of this workbook.

These family activities were developed by the engineers and educators (and parents, sisters & brothers, aunts & uncles) of Ten80 Education.

Visit www.Ten80Education.com and www.FastTrackRC.com to learn how your community schools and organizations can help extend the learning experience with Math2Go Challenges and FastTrack RC, a NASCAR STEM* Youth Initiative.

*STEM = Science, Technology, Engineering & Mathematics

What does NASCAR have to do with science & math?

Hendrick Motorsports is one of the foremost stock car organizations that has four NASCAR Sprint Cup Series racing teams, including the famous Jeff Gordon, Jimmie Johnson, Dale Earnhardt Jr and veteran Mark Martin. They hire dozens of engineers to support these teams because they know that setting their car up right for each race is as important, if not more, than what the driver does.

Start with the most basic law of motion described first by Sir Isaac Newton. Mathematically, this 2nd law of motion is probably the world's most famous equation.

$$F = ma$$

This equation says that the force (F) required to move something is directly proportional to its mass (m) and inversely proportional to the acceleration (a). With respect to racing, this means that a lighter car accelerates faster than a heavier, more massive car. Based on this law, you might think that light cars are best; unfortunately, the truth isn't so simple. Everything in racing is a trade-off.

The heavier car accelerates slower but is more stable and therefore easier to control and steer. Figuring out the best compromise between acceleration and stability is an optimization problem. The solution to this problem, as with every aspect of setting up your car, depends on the driving course and can only be figured out by collecting data, evaluating it and creating math models.

So now you know, racing is a game of balancing one trade-off with another. For engineers and whole race teams to do that, they have to first understand the basic laws of motion and how work is done by simple machines that are combined in all sorts of ways to make the multitude of compound machines inside of their car.

Of course, once the car is engineered and fabricated, crew chiefs help figure out how to set it up and how to keep it performing over the grueling races like the Bank of America 500 at Charlotte Motor Speedway. In this Fall race, drivers go just over 500 miles, over 334 laps around the 1.5 mile track. There is a lot more strategy than you can imagine that goes into making a winner. This is where literally the rubber hits the road and thousands of man-hours of design, work and practice are put to the test.

Tune in on Saturday, October 16th, 2010 to see who will win the Bank of America 500. Use the final activity in this workbook to track your favorite driver's performance.

NASCAR Sprint Cup Series Primer

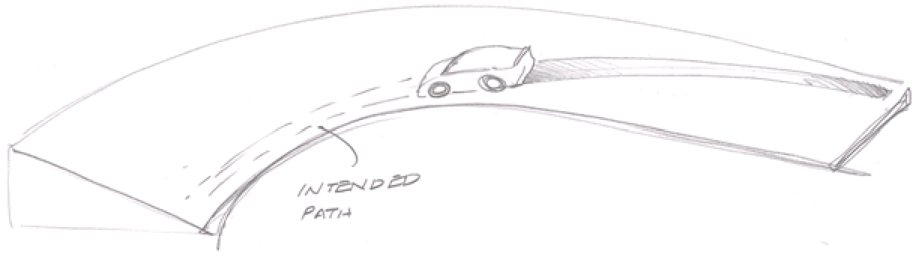
What to look for when watching the Bank of America 500 & other races

If you're new to watching NASCAR races, there are a few terms you should understand because commentators will say them over and over. The jargon includes words like loose, tight, wedge and track bar. All of these terms refer to how the car handles or how to change its handling. Though the actual analysis teams do before and during races to make their decisions is very sophisticated, the basic underlying idea behind how a car handles is pretty simple.

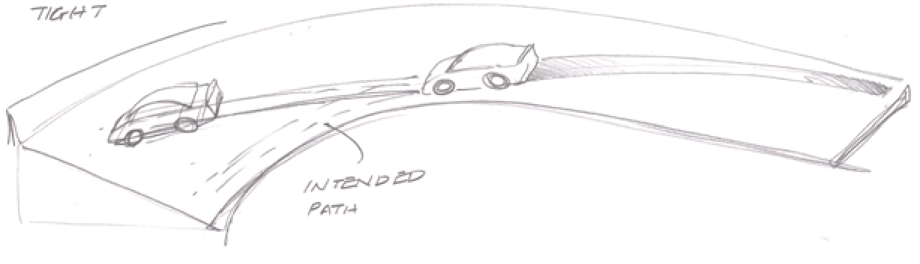
Loose & Tight Handling

The whole idea of racing is to drive at the very edge of control all the time. If you're not driving at the car's limits then another car is passing you. If you're over the limits then you wreck.

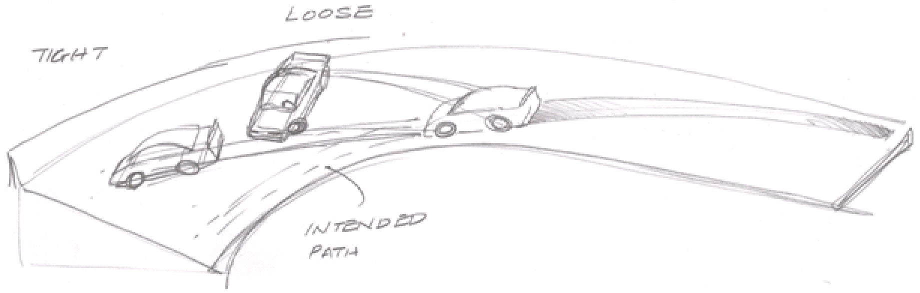
As a car enters a curve, the driver is targeting a certain path, but it doesn't always happen as planned. When drivers and commentators say the car is 'tight', they mean it is rotating less than expected. It under-rotates and heads for the wall instead following the intended curve because the front wheels don't have enough traction compared to the rear wheels.



Of course there is the opposite condition too. The rear wheels don't have as much traction as the front and the car over-rotates (spins out) as the back tires try to pass the front of the car. When this happens the car is 'loose'.



If a car is either loose or tight, the driver has to slow down to avoid wrecking. Other teams that have better balanced cars can drive faster around turns and probably get ahead in the race.



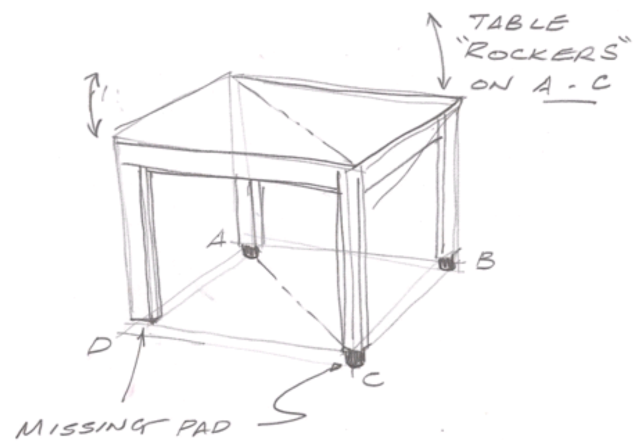
Diagnosing the Problem

So what is the right balance? Though there are literally thousands of small ways NASCAR teams can adjust the balance of their car, the underlying idea is pretty easy to understand. A pretty basic understanding is all you need to enjoy watching the teams compete.

During testing in the weeks and months leading up to a race, teams use very advanced and expensive data collection and analysis technology including:

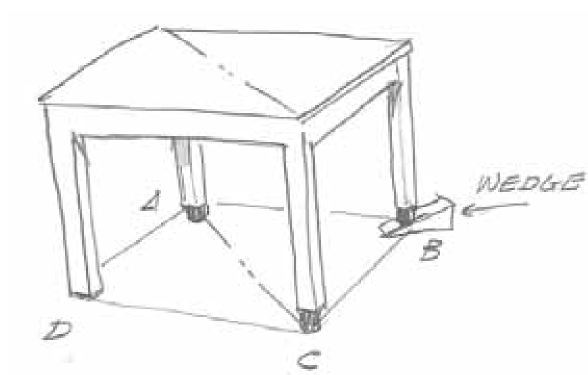
- Wind tunnels to test aerodynamics and to route air around the car for cooling
- 7-post rigs that move and shake real cars exactly as if they were driving on any one of the tracks
- Sensors all over the car that collect and transmit data on temperature, pressure, torque, etc.

During a race however, the only real feedback for teams on how the car handles is from its driver. Listen during a race to hear how different teams communicate. Some of the best drivers literally tell the crew how the car handles at 6 distinct spots around every turn - entry, exit and 4 places in between. Once a team decides to loosen or tighten the car during a pit stop, they have to figure out which way to modify the car.



Weight Balance

You can draw from your own experience to understand weight balance. Have you ever been to a restaurant where the table is 'tippy' because one leg is too short?

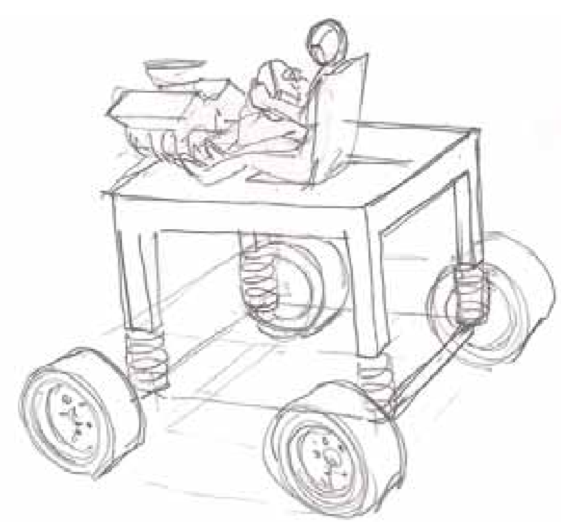


The table actually rocks on two of the legs, labeled A and C in the sketch. Theoretically, these two legs carry the entire weight of the table so there's no load on legs B and D.

You can easily fix the tippy table by placing a wedge under one of the dangling legs, B or D. Depending on the wedge you use and how you place it, the final weight distribution on all legs can vary a lot.

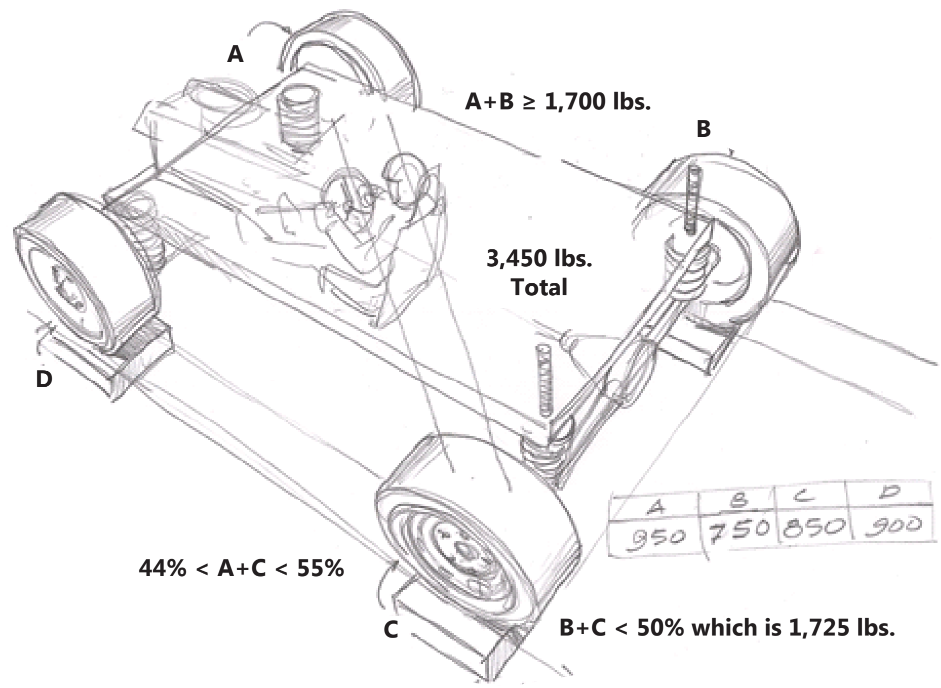
During a pit stop when you hear someone comment that they've "added wedge" to the car, this is essentially what they're doing.

Now that you have a baseline idea of weight balance, we can begin to complicate our picture so it aligns a little better to NASCAR cars and teams. In a NASCAR race car, all four corners are sitting on springs which sit on wheels.



One more change completes the (somewhat silly) picture. The chassis does ride on a spring at each corner, but those springs are on top of wheel axles. We'll shorten the 'legs' from here on too.

The car is weighed by placing a scale (an oversized bathroom scale) under each wheel. The "weight balance" refers to the fraction of the total weight carried by each wheel.

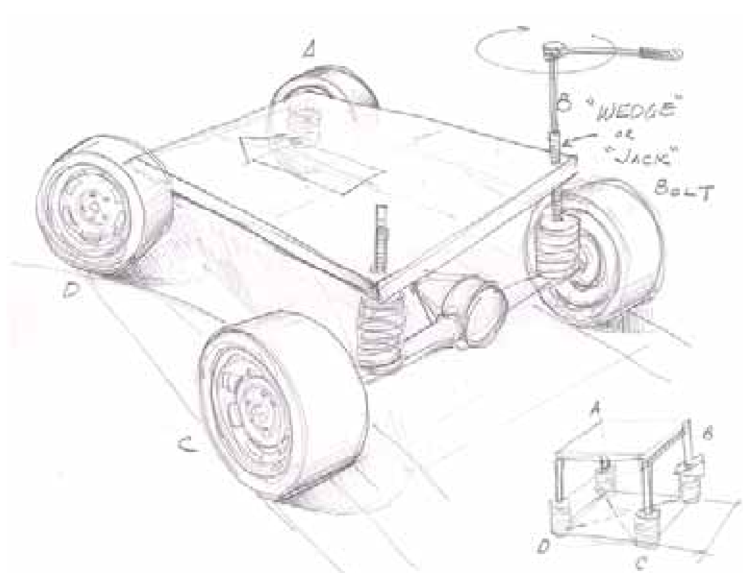


There are rules about weight and weight balance in the NASCAR Sprint Cup Series. Cars are inspected just before races to make sure they adhere to these and many others:

- Total weight is at least 3,450 pounds including oil in the engine and gasoline in the tank.
- The back wheels, B and C, together must carry less than 50% of the total car weight.
- The two right side wheels, A and B, together must carry at least 1,700 pounds.
- The right front and left rear wheels, A and C, together may carry a combined weight between 44 and 55% of the total car weight. A plus C is also called "cross weight".

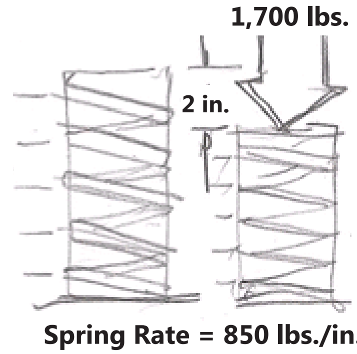
So if a driver says the car is loose, here is one possible fix.

Just as with the tippy table, this image shows the corner marked B 'jacked' up by putting a wedge under the leg. The same is done with a race car except instead of putting a wedge shaped object under the spring on corner B, the 'wedge bolt' or 'jack bolt' is screwed down having the effect of lifting the corner of the car. This increases the fraction of weight carried by B plus D and decreases the fraction of weight carried by A plus C.

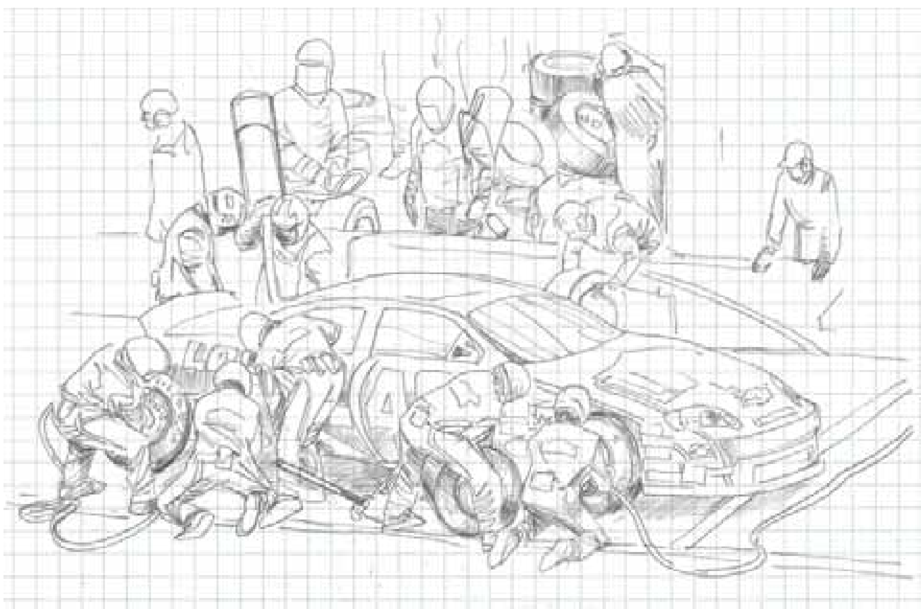


Springs in Specific

Teams choose different springs to install for every race because every track is different. The big difference between springs is how hard it is to compress them. This 'spring rate' is figured out by adding a known weight to the spring, measuring how much it compresses then dividing the weight by the distance it compressed (units are weight/distance). For example, a loose spring would compress 1 inch if you add 100 pounds to give a spring rate of 100 pounds/inch. A stiff spring would take 2,000 pounds before compressing an inch for a spring rate of 2,000 pounds/inch.



You can also think of the tires as 'balloon' springs so each corner of the chassis essentially sits on a compound spring (one spring on top of another). It is also pretty common for teams to adjust the effective spring rate by changing tire pressure. Changing the tire pressure by 1 psig* is like changing the spring rate of the steel spring by 60 pounds/inch.



NASCAR Sprint Cup Series Strategy

Listen during the Bank of America 500 to hear all of the different strategies teams devise. How much gasoline to add and when? What changes if there is a caution flag and you're not allowed to pass for a few laps? How many tires to take and when because cars go faster with fresh tires, but adding more tires adds valuable time in the pits?

Everything in racing is a trade-off. By changing something here, you're impacting many other things over there. Famous drivers only have the chance to win if their team makes the right decisions in the weeks and months leading up to a race and on race day itself.

Use the Bank of America 500 Performance Activity to track your favorite driver and listen to see what they are doing along the way. If you aren't already, you'll soon be hooked on this game of strategy, speed and teamwork.

* 1 psig stands for 1 pound per square inch-gauge; the gauge means it is above atmospheric pressure

Bank of America 500 Performance

Activity to Track Performance of Your Favorite Driver

Materials: Graph paper & pencil OR computer with spreadsheet

Purpose

There are NASCAR officials that track and communicate a lot of race data. This data is what crew chiefs use to make decisions about how their driver is doing and help decide what changes should be made when. Some of the big questions they answer with this data include:

Are we gaining or losing on the leader?

How fast are we gaining or losing?

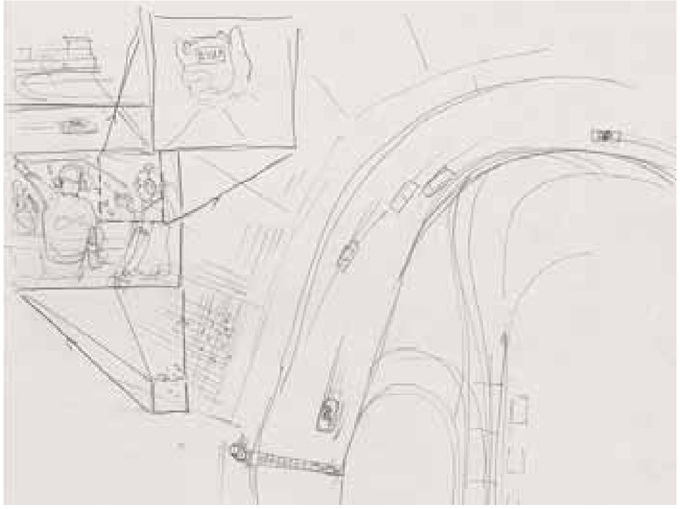
When will we be lapped or take the lead?

When should we pit & what should we do?

Some of that data is available to you as a spectator. While watching the 2010 Bank of America 500 on Saturday, October 16th, track the performance of your favorite driver to see if you can follow the decisions the team makes.

Procedure

1. Choose a driver and record the car number, driver and main sponsor on your data sheet.
2. Prepare your data sheet and graph. Use the one provided or set up your own on paper or computer.
3. During the race,
   - » Record: Lap number, Position in the field (1st, 34th, place etc) and time lag behind the leader (seconds)
   - » Make notes about what's happening including pit stops, caution, crashes, etc.
   - » Graph two series on the same graph as shown to the right. Use different shapes to symbolize each series (remember to label which shape is which series)
     * Series 1: lap number vs. position
     * Series 2: lap number vs. time lag
   - » See if you can understand why crew chiefs make the decisions they do.

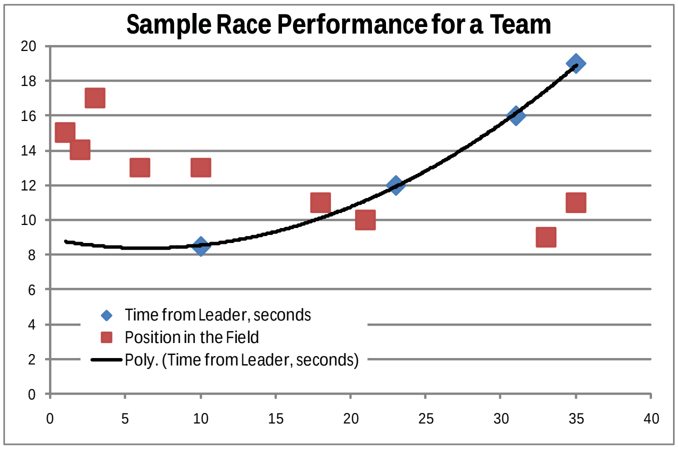


Where is the data?

If you don't have Track Pass or subscription to a service that provides the NASCAR feed, then get your data from the TV screen where a crawl bar above the racing action gives real-time information. The crawl bar shows position on track and sometimes, but not always, the time lag behind the leader.

The format is (position), (car number), (driver name), and if displayed, (time interval to the leader).

Time lag behind the leader is the one you may or may not see all the time. Some broadcasts give the data for every 5, 10 or even as little as every 20 laps.



What do you see in this graph?

At least one thing to note is that this team is gaining in position but actually losing time on the leader. The leader was pulling away from the main field.

Bank of America 500 Driver Performance

Race: Bank of America 500 Date: Saturday, October 16, 2010 Location: Charlotte Motor Speedway

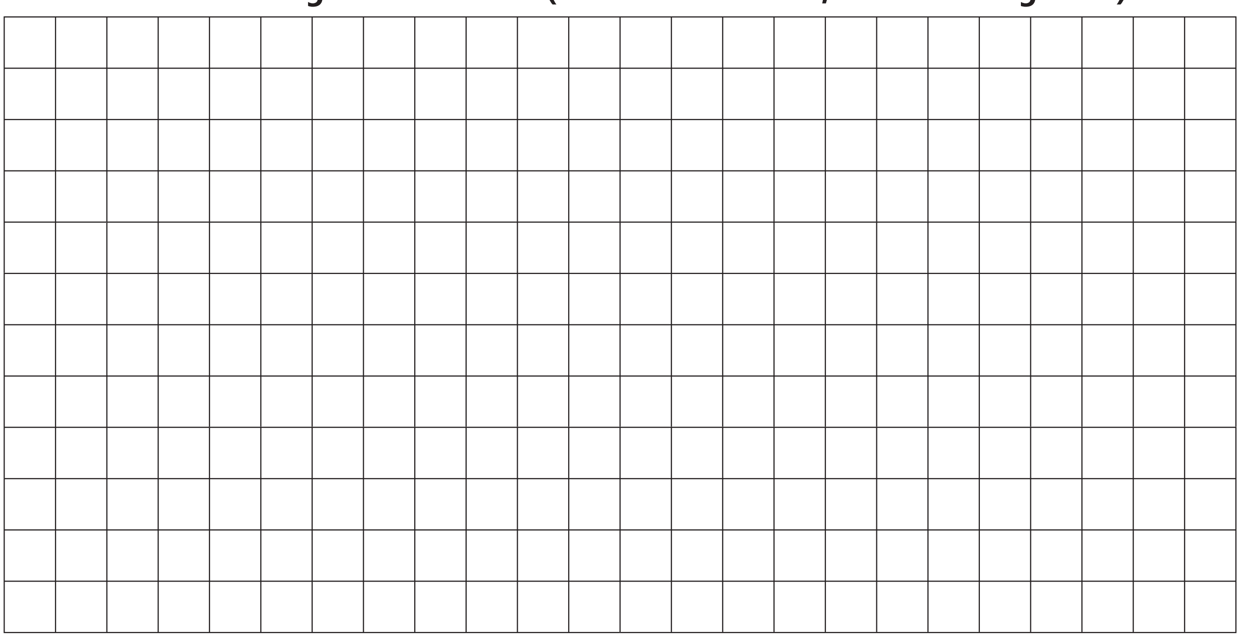
Driver: ________________________________ Number: __________ Sponsor: ______________________

Lap	Position	Time Lag

Lap	Position	Time Lag

Lap	Position	Time Lag

Position & Lag Behind Leader (Series 1 = Position, Series 2 = Lag Time)



Lap Number

Measurement 9-Ball

Introduction Activity

Materials: Tape measure, kitchen weigh scale

ESSENTIAL QUESTION: What are some measurements and units?

ENGAGE: Exercise your scientific innovation by brainstorming about how you could determine the dimensions of a piece of paper, its height, width and depth (depth is of course the tough one). Work on your own for a minute or two then come together and share your ideas. Try different ways then talk about the best units of measure for 1, 100 or 10,000 pieces of paper[K].

EXPLORE: Find nine different objects, each with a different magnitude of measurement so that each integer from 1 to 9 is represented. The units can be standard or metric but as always you have to write it down. Begin by estimating then actually measure the size of your objects (make a race out of it).

Example: Estimate a tomato is 1 pound, rice kernel is 2 mm long, etc. Actual values are 0.8 pounds, 4 mm, etc.

Item	Estimate Magnitude	Unit of Measure	Actual Measurement
Example: Tomato on counter	*1*	*pound*	*0.8 pound*
	1		
	2		
	3		
	4		
	5		
	6		
	7		
	8		

EXPLAIN: Units are absolutely critical! On July 23rd, 1983 an Air Canada flight, cruising at an altitude of 26,000 feet, completely ran out of fuel only halfway through its flight. All of its 61 passengers and crew survived the crash landing thanks to a very skilled pilot, but it was very nearly a huge disaster. There were no fuel leaks or engine malfunctions, but rather a unit conversion mistake that led the grounds crew to add too little fuel. The flight required 22,300 kilograms of fuel and there was already 7,682 liters in the tank. Rather than figuring out how much fuel to add by converting volume in liters to weight in Kg, they converted to weight in pounds. They should have used a density value of 0.803 Kg / 1 liter of jet fuel but instead used 1.77 pounds / 1 liter of jet fuel. Ooops!

NASCAR teams are also obsessed with measurements. The shape of their car is mostly determined by NASCAR rules which dictate that each team fit their car body to the contour of 30 templates. For instance, the biggest template fits over the center of the car from front to back. When the template is laid on the car, the gap between the template and the car cannot exceed the specified tolerance. Each template is marked on its edge with a colored line. If the line is red, then the gap must be less than 0.07 inches (0.18 cm). If the line is blue, the gap must be less than 0.25 inches (0.64 cm). If the line is green, the gap must be less than 0.5 inches (1.27 cm).

EXTEND: Think about bigger items with measurements of 10, 20, 30, 40, etc. What about 100, 200, 300, etc.? ALWAYS state the unit. Look up (internet) actual values for items you can't measure.

Pi in the Sky

Introduction Activity

Materials: Flexible tape measure like a seamstress uses or string & meter stick

ESSENTIAL QUESTION: What is a circle?

ENGAGE: Look around you and name some things that are circles. Distinguish between circular items and real circles. For example, a tomato isn't a circle but a cross-sectional slice of it is close. A round cookie tin is actually a cylinder but a cross-sectional slice of it (look down at it from the top) is a circle.

Define what a circle is. In Euclidean geometry, a circle is the set of all points in a plane at a fixed distance, called the radius, from a fixed point, the center.

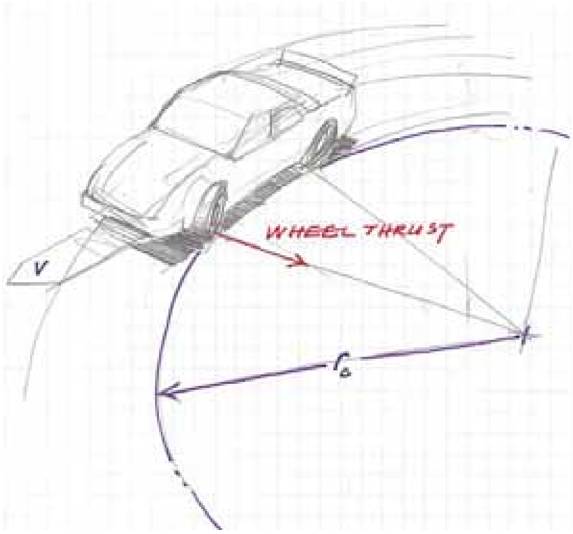
Now think about circles in nature. On paper, make a race out of it and name as many circles either in your sight or in nature that you can in 60 seconds. Look at each other's list and talk about them. For example, we see the Sun rising over the ocean as a circle, but is it? Of course not.

EXPLORE[K] Use a flexible tape measure or string stretched along a meter stick to measure a selection of round objects. Record the distance around (circumference), distance across (diameter) and the ratio of circumference to diameter (divide the distance around by the distance across).

Is the ratio the same or very nearly the same every time[K]? How different is it each time[K]?

ITEM	AROUND (circumference)	ACROSS (diameter)	RATIO: AROUND ÷ ACROSS

EXPLAIN: Discuss how the various round objects have different measurements but the same (or nearly the same) ratio: 3.14159... Sometimes this special number (pi) is described with the ratios 22/7 or 355/113 which was used by the Chinese as far back as 300 AD.



NASCAR tracks aren't circles, but when team engineers are designing their car to go the fastest around turns, they consider how the car turns on circles. To calculate the fastest possible speed on a turn you have to know the turn radius (and Newton's Laws of Motion). Think about when you are in a car or bus and are exiting the highway on a circular ramp. If it is a tight turn, you have to slow down a lot. If it is a pretty wide turn you don't have to slow down so much. The highest speed you can go is indirectly related to the radius of the turn you're on. You'll do more with this idea when we talk about NASCAR track banking.

EXTEND: Can you run faster on a circle with a small radius or large one? Try it. Run around a chair on a radius of 3 ft, then 6ft, then 10 ft.

In the Blink of an Eye

Introduction Activity

Materials: stopwatch (try a free cell phone app if you don't have one)

ESSENTIAL QUESTION: How fast can humans react?

ENGAGE: Can you time an eye blink? Use a stopwatch to try it. If your reaction time is less than 0.15 seconds, the blink is quicker than you can push the button. An eye blink averages about 15 hundredths of a second. It is interesting to note that the average person spends about 23 minutes in darkness daily due to eye blinks. This may be why the brain has learned to "fill in the blank spaces" for us on occasion. It may be why "eye witness" testimony is not considered the best source of evidence. It may explain why several witnesses to the same event will have "seen" different things.

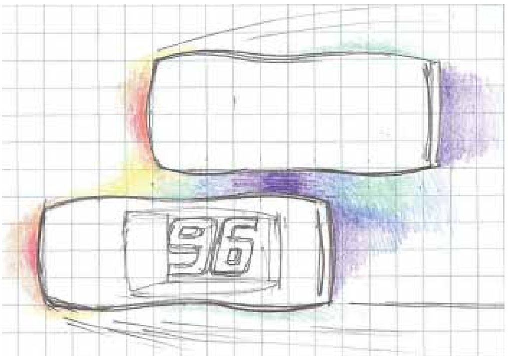
EXPLORE: Using a stopwatch, start and stop it so it reads as close to 5 seconds as possible. In the table to the right, record the time even if you didn't stop it right at 5 seconds. Write down all the decimal places the watch shows. Repeat 5 times.

What is the average of your measured times? Calculate it by adding up all the measurements and dividing by the number of measurements you have (5 in this activity).

The difference between the highest and lowest numbers is called the range. Find it by subtracting the lowest from the highest number.

Trial	Time (seconds)
1	
2	
3	
4	
5	
Average	
Range	

EXPLAIN: Just like you can't use a meter stick to measure the size of a dust mite, humans aren't very good tools for measuring the movement of fast objects. Galileo and a lot of people before him had a lot of trouble measuring acceleration due to gravity because they were trying to measure the speed of falling objects without having the technology of watches and stopwatches. Even today, when we have this technology, we can' t always agree.



NASCAR teams may win a 500 mile race by less than 0.01 of a second which at 200 miles per hour (3,250 inches per second) is just under 3 feet between bumpers. Though you'd think you could notice that distance, at that speed it is next to impossible. NASCAR therefore uses photo finishes as do horse racers. Other sports like soccer and hockey are incorporating more immediate and (hopefully) reliable technology to let you know if the ball or puck 'breaks the plane' of the goal.

Accurate means "capable of providing a correct reading or measurement." In physical science it means 'correct'. If your average times were closer to 6 than 5, your measurements were not very accurate. A measurement is accurate if it correctly reflects the size of the thing being measured. Precise means "exact, as in performance, execution, or amount. "In physical science it means "repeatable, reliable, getting the same measurement each time." We can never make a perfect measurement. The best we can do is to come as close as possible within the limitations of the measuring instruments.

EXTEND: How long do things take? Use your stopwatch to measure how long it takes to say your A-B-C's, to run up the stairs, to clean the dishes.

Build a Track

Pythagorean Theorem & Triples

Materials: tape measure, rope that does not stretch, tape, graph paper, something to race

Draw Your Track

Think about a track on which you would like to race an RC car, skateboards or roller skates. Draw it on graph paper so that it has a rectangular outside and dots (cones) to mark the inside features. Connect the dots to make the actual course. Make a scale for your track map to show how many squares represent each foot in real life (example: 2 squares = 5 feet). How long and how wide is your track?

How to Lay it Out

The key to laying out a track is to see the image as a Cartesian coordinate system. The track layout is a map organized on a grid system. Each point on the track layout is a coordinate on the grid system.

Step 1: Map the Track

In this example, the origin is in the upper right corner and points right and down from the origin are positive. How you orient your track depends on the physical space.

To make your Cartesian Map,

1. Define an origin (0,0) point.
2. Define the directions for positive and negative movement along the X and Y axes.
3. Label the track points relative to the origin.

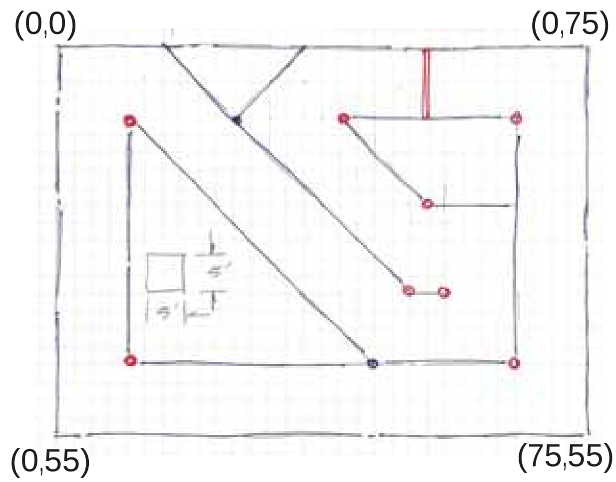
Step 2: Layout the Outer Rectangle

Layout the corners of your full-size rectangle on the ground. Make sure the four corners are square (90°) using a multiple of the 3-4-5 triangle, 12-16-20.

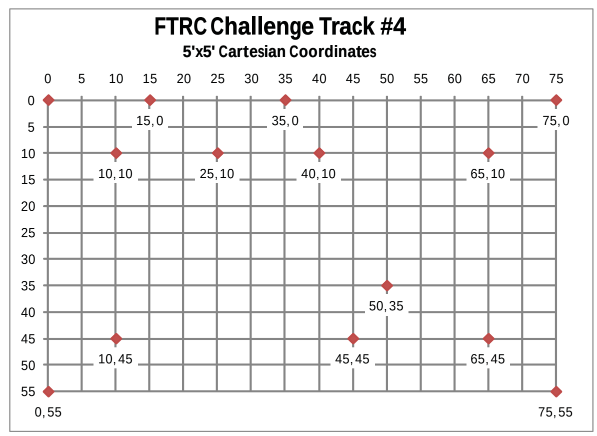
Cut three pieces of rope then tape them together to make a circle. Once taped together, the three parts should be 12 feet, 16 feet and 20 feet long.

Pull the rope tight so that that the two short sides are along the outside of the track. Put tape marks on the ground along the two short sides. Remove the rope then tape down the track boundary on that corner.

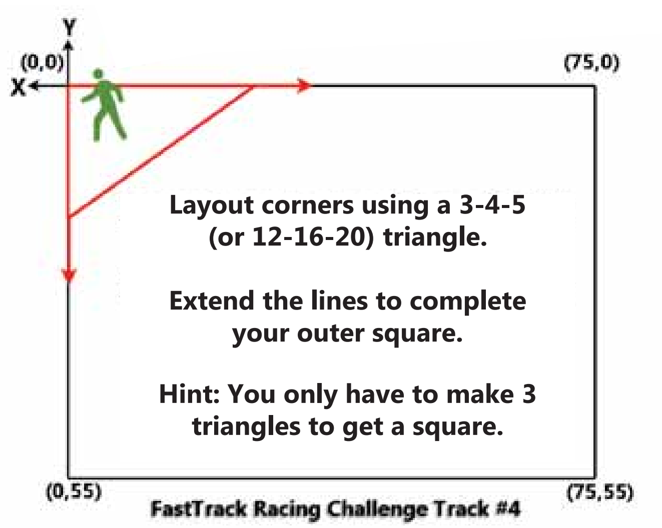
Repeat for three of the four corners then tape down the outer, rectangular boundary for your track.



(Above) Track layout. Make your own version.
(Below) Cartesian map of the track



(Below) Use 3-4-5 triangles to make sure your corners are square (meaning they are actually 90 degree angles).



Step 3: Mark Grid Lines

Make the grid lines on your Cartesian coordinate system. Along the X and Y axes, put a piece of tape every five (5) feet.

Step 4: Plot Each Track Point

Mark each dot on your track. For example, there are points along the X-axis at (15,0) and (35,0). There are points at (10, 10), (25,10) (40,10) and (65,10). Mark them all.

Step 5: Connect Dots to Make Lanes

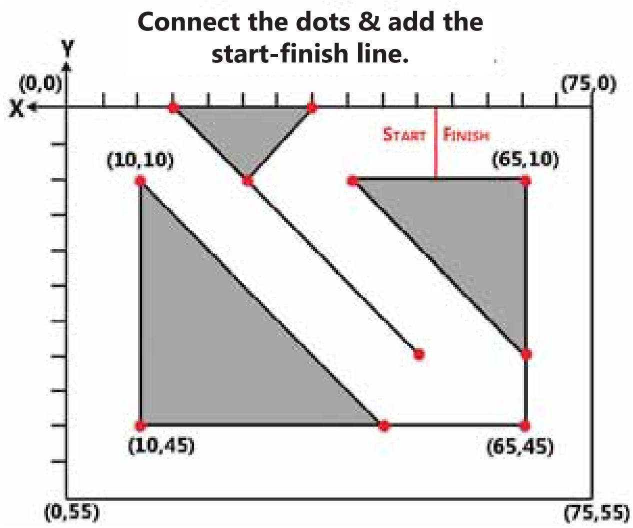
Connect all of the dots so that the lane boundaries match the track layout drawing. Put cones over each point to make the drive path more clear.

Step 6: Finishing Touches

Put cones over each point to make the drive path more clear. Mark the Start-Finish Line.

Last Step....RACE!

Be safe and have fun racing on your new road course.



3-4-5 Triangles (Pythagorean Theorem)

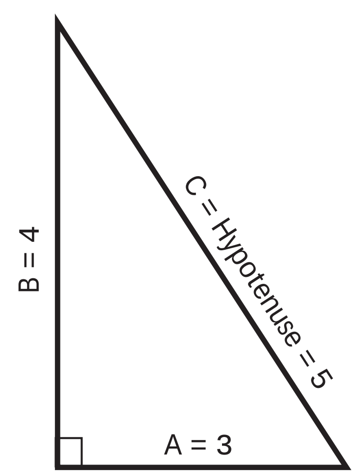
Over 4,000 years ago, before Pythagoras (569 - 475 BC) came along and formally advanced geometry as a scientific study, the Egyptians used the principal of 3-4-5 triangles to build the Great Pyramids.

3-4-5 are Pythagorean triples, meaning that they represent three sides of a right triangle. If the three sides are 3, 4 and 5 units in length, the angle between the 3 and 4 sides will be a right, 90° angle. 3, 4, and 5 are very convenient, whole numbers to work with, but there are many combinations that give a right triangle. The Pythagorean Theorem describes the relationship.

Pythagorean Theorem: $A^2 + B^2 = C^2$

where A and B are two sides of a triangle and C is the third, longest side called the hypotenuse.

Any multiple of 3,4 and 5 give you a right triangle. 6-8-10 and 12-16-20 give you a 90° angle. These bigger sides make it easier to extend the sides into long lines when you're laying out something physical like a track or deck.



Pythagorean Theorem: $A^2 + B^2 = C^2$

A=3, B=4 and C=5 is a convenient set that complete this equation.

Move It!

Activity on Speed & Velocity

Materials: ruler or tape measure, stopwatch, tape or objects to mark spots

ESSENTIAL QUESTION: What is average speed and velocity?

ENGAGE[K]: Setup your demonstration track. With ruler in hand, stand against a wall with open space in front of you. Walk in a straight line out from the wall and place a marker at five (5) and ten (10) feet from the wall. Now, these directions may seem silly given what you just did....but we're making an important point.

Directions: Count and record the number of steps it takes for each move. Walk to the first marker. Stop. Walk back to the wall. Stop. Walk to the second marker. Stop. Walk back to the first marker. Stop. Fill in the table below and answer these questions. What was the total distance you moved and how did that compare to your displacement from the wall[K]? Displacement is the ultimate change in position.

MOVE	STEPS	DISTANCE	DISPLACEMENT FROM WALL
WALL - 1ST MARKER			
1ST MARKER - WALL			
WALL - 2ND MARKER			
2ND MARKER - 1ST MARKER			
TOTAL			

EXPLORE: Remove the first marker on your demo track and think of different ways you can travel a ten foot distance (run, skip, walk, duck-walk, hop, roll in a chair, drive an RC car, etc.). Now try them and use a stopwatch to measure how long it takes to travel one ten foot long lap.

MOVEMENT	WALK	HOP	RUN			TOTAL
TIME IN SEC.						
DISTANCE	10 ft.	10 ft.	10 ft.	10 ft.	10 ft.	
AVG. SPEED						

What is the average speed for each lap and over all laps combined?

Find the average speed of each "lap" by dividing lap distance by lap time (Distance ÷ Time).

It takes a few steps to figure out the average speed over all laps combined.

- Get the total time of travel by adding the times from each individual lap
- Get the total distance traveled by multiplying the lap distance by number of laps.
- Finally, calculate the average speed by dividing the total distance by the total time (Dist. ÷ Time).

EXPLAIN: If you look up the speeds at Charlotte Motor Speedway, home of the Bank of America 500 NASCAR Sprint Cup Series race, you find all kinds of numbers. Even looking for top record speeds, you get different values. For example, Jeff Gordon holds the record for top average speed over a Bank of America 500 race at 160 miles per hour (1999). The record qualifying speed (single lap) was set in the year 2000 by Dale Earnhardt Jr. at 186.034 miles per hour. Cars at Charlotte Motor Speedway actually hit instantaneous speeds of around 210 mph.

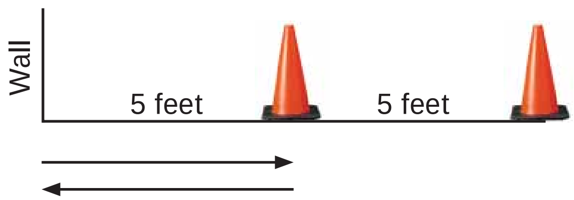
The definition for speed is always the same, but you can look at speed in an instant or average speed over long distances or short distances like a lap.

Velocity....now that's not a term we don't hear as much in day-to-day talk about NASCAR racing. It is important to understand the difference in these terms even though we mistakenly use them

Speed is a "RATE at which an object (you) covers a DISTANCE", calculated simply as distance ÷ time. In calculating speed, where that distance takes you (or any object) doesn't matter.

Velocity is a vector quantity that refers to "the RATE at which an object changes its POSITION". In the first two moves of the engage activity, you returned to the starting position so your net velocity was ZERO! You were right back where you started when you began - your net displacement was zero and so was your net velocity. Speed on the other hand was the full 10 feet moved divided by the time.

After 1st two moves

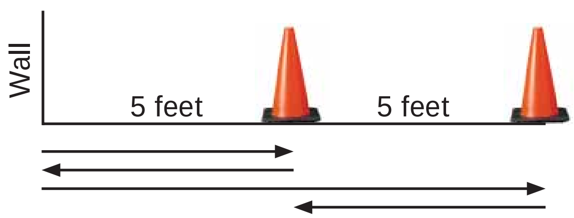


Distance = 10 ft.
Net displacement = 0 ft.
Avg. Speed = (10 ft. ÷ total time)

Net Velocity = (0 ft. ÷ total time) = 0

After all four moves your ultimate displacement was +5 feet so your net velocity was the total time it took you to walk, divided by the 5 feet you actually moved in the end. The speed was all 25 feet divided by the total time.

After all 4 moves



Distance = 25 ft.
Net displacement = 5 ft.
Avg. Speed = (25 ft. ÷ total time)

Net Velocity = (5 ft. ÷ total time) in a straight line away from the wall

Did You Know?....

In 2005, Elliott Sadler set the Charlotte Motor Speedway track record, clocking in at 193.216 miles per hour over one lap. Speeds at Charlotte Motor Speedway jumped nearly five MPH from the previous year after the track was smoothed and repaved.

EXTEND^K: Charlotte Motor Speedway in Concord, NC is an oval track that's 1.5 miles long. If an average speed over the course of a race is 180 mph, and the race is 334 complete laps, what is the total drive time? What is the net velocity of cars after crossing the finish line?

NASCAR Numbers

Professor Pi's Note on Racing Facts

Qualifying: Its all about time!

To figure out which car is in what position on race day, NASCAR teams drive in qualifying laps. The fastest car gets the front spot, called the 'pole position'. Others are lined up in order of their finish or sent off to pack up their trailer and go home. Though the car with the highest average speed over one lap is the winner, nobody talks about speed on qualifying day. NASCAR Sprint Cup Series cars don't even have speedometers! It is a team's lap time that determines their place in the race or an early trip home.

Race Day: Go the distance!

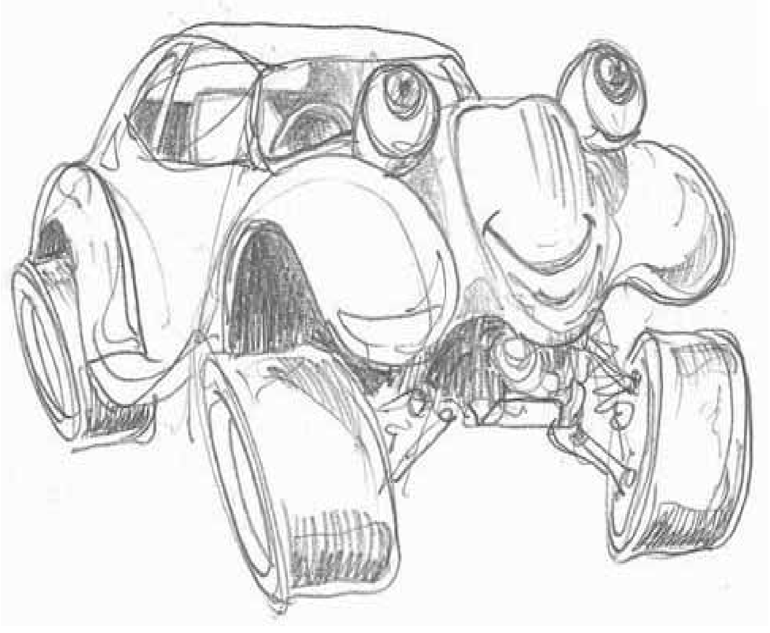
The Bank of America 500 – that's 500 miles and 334 complete laps on a 1.5 mile track. Each lap averages 180 mph and can be completed in about 30 seconds. If you measured the time for each 100 foot increment, you would find that the cars slow down a lot in the turns and speed up going down the straight-aways. Looking at these smaller distances, at the end of the straight away before they slow down, a car might reach 205 -210 mph. In the 100 feet in the corner the speed may be down to 160-165 mph.

Pit Road: Don't Speed!

Really the only time NASCAR teams think about speed is during pit stops. Though teams do obsessively measure down to the hundredth of a second how long the pit crew takes, that's not what we mean. When teams pull off of the track and onto pit road, they have to stay under a speed limit. Because NASCAR cars don't have speedometers, there are a series of markers and drivers can't go past them faster than the allotted time (usually 6-8 segments). Officials calculate and report the car's average speed for each segment (distance ÷ by time in a segment) and get a penalty if they exceed the limit.

Where are You[K]? Position is defined as the location of an object in a frame of reference. Think about it and answer the question, Where are you?

Why, I'm here, of course; every place I go, I'm always there.



Position: the location of an object in a frame of reference

Speed: a change in position in some amount of time, it is a rate and has units of (distance/time); the distance from one Position to the next is usually measured along a straight line, or simple curve, e.g., a circle.

Velocity has both speed and direction. It describes a change in position.

Falling Faster

Activity on Gravity & Acceleration

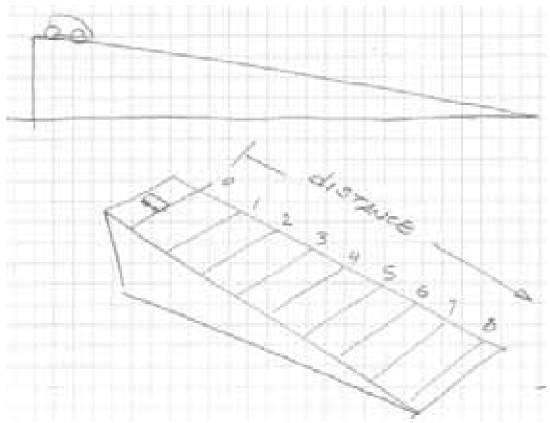
Materials: ruler or tape measure, stopwatch, small model car (like Hot Wheels), stuff to make a ramp, more than one person

ESSENTIAL QUESTION: When is an object accelerating?

ENGAGE: Talk about past experiences riding a roller coaster and/or show a brief video of roller coaster rides at www.KingsDominion.com. (We'll wait.....)... There are some exceptions of course, but when riding on a coaster you're almost always changing either your speed or direction. That means you're almost always accelerating. The rate at which the speed or direction changes is referred to as acceleration. What you experience on a thrill ride is actually the really dramatic accelerations...think about it. When riding in a straight line, at an unchanging speed it isn't very exciting. It is the speeding up and slowing down, the twists and turns that make it so fun. In reality, roller coasters are the closest most of us will get to experiencing the force of acceleration that NASCAR drivers feel during races or even tests.

EXPLORE: Use a modern version of Galileo's experiment to learn some more about acceleration. Acceleration means a change in velocity; that means a change in speed or direction. Galileo was not able to measure the time it took objects to fall straight down because they moved too fast for his "clocks" to measure. He found that he could however time objects rolling down inclined planes. He also found that the patterns he observed helped explain how the speed of a falling object changes over time.

Recruit at least one co-researcher. Make a ramp and mark off every 1 foot as shown to the right (longer the better).



As the small scale car rolls down the ramp, measure the time it takes to cross each line. If you only have 2 people, you'll have to release the car five times to get a measurement for five marks; 8 times for 8 marks, etc..

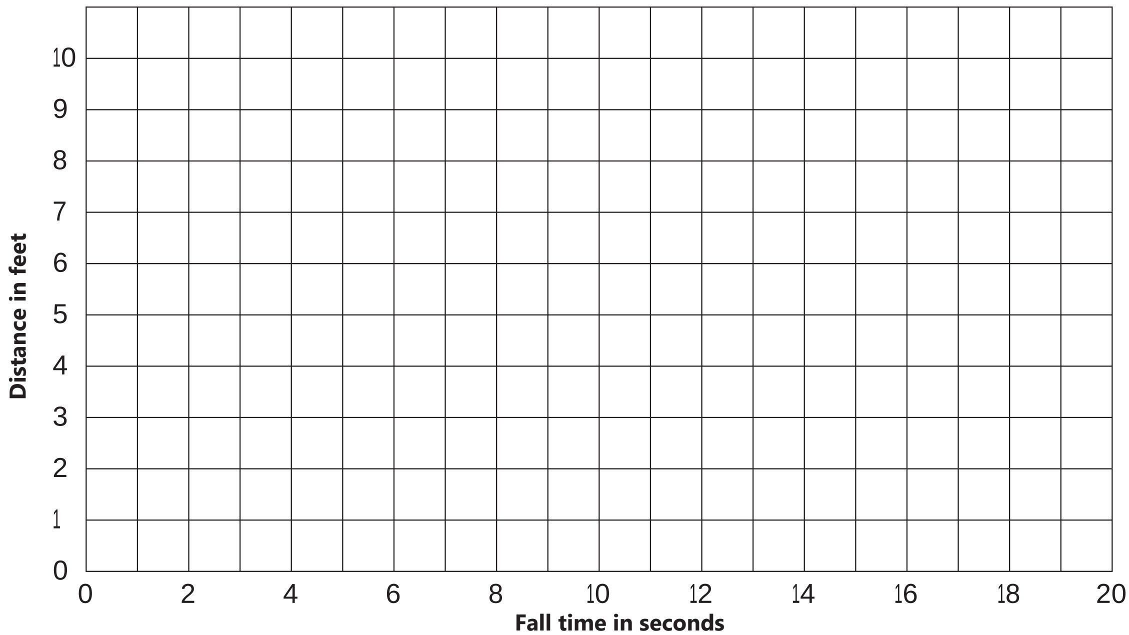
Repeat until you have fairly consistent times for each distance. Use the average (if you have 3 measurements for the 2 ft. mark, average them to get a good measure for how long it takes to fall 2 feet along the ramp).

Square the average time and enter into the bottom row of this table.

DISTANCE IN FT.		1	2	3	4	5	6	7	8	9
DROP TIME IN SEC.	TEST 1									
	TEST 2									
	TEST 3									
AVERAGE TIME										
TIME^2										

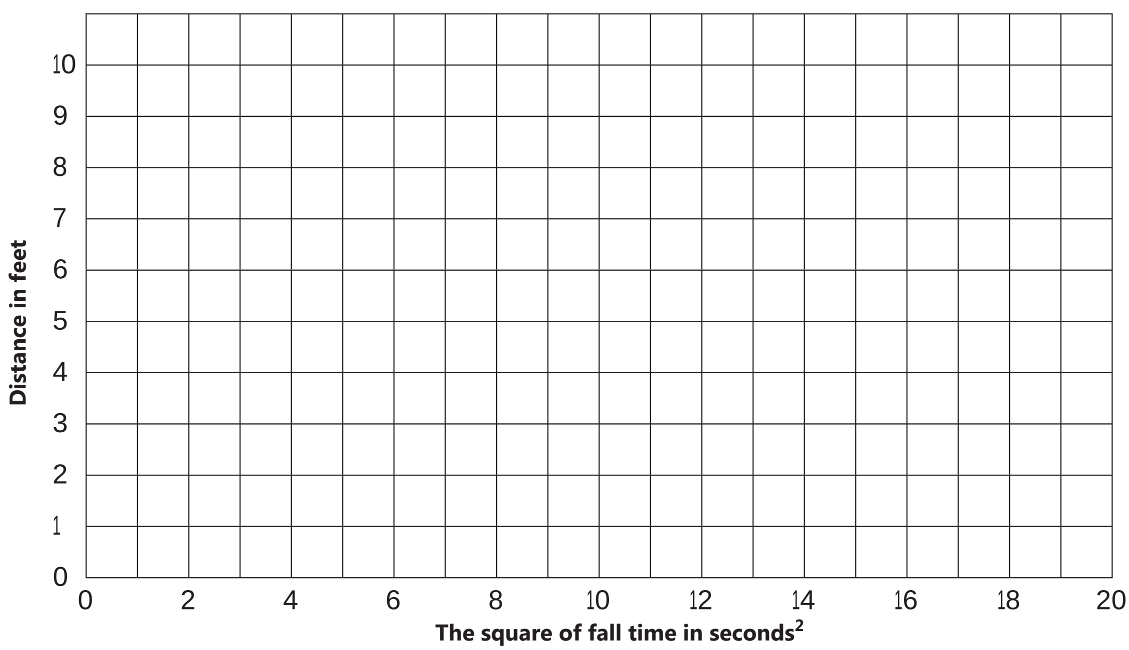
EXPLAIN: Scientists, politicians, NASCAR crew chiefs and almost anyone trying to answer tough questions looks for patterns to help reveal them. When Galileo was trying to figure out how gravity worked, he didn't have all of the tools we have today like Cartesian Coordinates and algebra, both of which are the basic tools we use today to find patterns in data. To reveal patterns in how gravity works, use the graph on the next page to plot distance vs. time. This graph helps answer the question of how distance changes with time.

Distance fallen down the ramp over time



Galileo found that there is a relationship between the square of time and the distance an object falls. If it falls twice as long, it travels four times as far. At three times the time, it falls nine times the distance. Gravity is pulling the object toward the center of the Earth at a very steady pace: velocity increases 9.8 meters /second every second. Graph the distance fallen vs. time squared (X=distance, Y=Time^2)

Distance fallen down the ramp over the square of time



EXTEND then EXTEND FURTHER[K]: Compare data and patterns between all of your sets.

- Roll marbles and compare this data with all previous data.
- Use books to raise the ramp (or lower) then repeat at two different angles of inclination.
- Tape washers on the car. Does weight affect times? If your data shows that it does, could it be added friction? Try it with heavier and lighter marbles.

A Change in a Change

Professor Pi's History of Math & Science Note

If you just completed the activity on gravity and acceleration, you were able to do something that took even the brightest minds hundreds of years to do. Your graph of distance and time-squared should reveal that distance of falling bodies increases proportionally with the square of time...what does that mean? Here's an example for a ball rolling down a ramp.

Roll Time	Roll Distance	What does that mean?
1 sec	1 feet	*Our initial speed, 1 ft/sec*
2 sec	4 feet	*2 times as long, 4 times as far*
3 sec	9 feet	*3 times as long, 9 times as far*

For you algebra learners, the equation of this line is represented as: $d = \frac{1}{2} a t^2$

where d = distance, a = an acceleration due to gravity and t is time.

It took famous scientists like Galileo so long to figure this out because they didn't have either Cartesian coordinates (Rene Descartes 1596 - 1650, doesn't invent analytical algebra until the 1644 time frame at which point Galileo had been dead for at least two years), nor the math skills to realize that "a" is not the acceleration down the incline but rather acceleration in a free-fall.

Without these tools we take for granted (and that too many people don't choose to understand), Galileo come up with some interesting (and wrong) numbers for the acceleration of gravity. Kepler had theorized the time-square relationship at least by 1595, but without the calculus of Leibniz and Newton and without the mechanics of the Bernoulli, the published values for gravity were all over the place.

By 1650 the debate over what was the correct value for gravity was hotly contested; in England the idea of the square relationship was well accepted, with Hooke (Newton's nemesis), Halley (of comet fame), and Wren (the architect) all in agreement in concept but no one had decent numbers.

In 1657 Fiar Marin Mersenne writes to Christiaan Huygens and asks ...

- Is there anything worthwhile in this Galileo business, and
- Can he get any real numbers out of it for what is the acceleration of gravity?

Huygens, spurred by his long-distance mentor, figures out how to build a pendulum that really is free of its structure and therefore free to fall like an object you'd drop straight down. Even still, he can't get any decent numbers because there's no such thing as a decent clock to measure seconds. Everyone agrees what a second is, but there's no machine to measure one. Clocks of the day only measure minutes and hours and even good clocks gain or lose as much as 30 minutes a day.

Take some time to look up Marin Mersenne. Throughout his lifetime Mersenne helped many potential scientists by steering them in the right direction and advising some on the next step to take.

He had some small or very big part in Galileo's, Newton's, Huygen's and even Descarte's lives. Good mentors are invaluable, true then and today.

It wasn't until 1797 that Henry Cavendish actually came up with a good value for acceleration due to gravity that was true completely independent of an object's mass.

Bodies in Motion...

Activity on Newton's 1st Law of Motion

Materials: scoooter or cart, plastic or paper cup, 2 plastic drink bottles, dollar bill, water

ESSENTIAL QUESTION: What is inertia?

ENGAGE: Fill a 20 oz. plastic bottle with water. Carefully place the bottle on top of another empty bottle with a dollar bill between them (on top of a towel just in case). What do you think will happen if you quickly remove the dollar bill like a magician pulling a table-cloth? Make a prediction out loud then give it a shot. The water should begin pouring from the top bottle into the other but the tower will soon become unstable and fall. Work together to explain what you observed (see an explanation below).

EXPLORE[K]: Place a half filled cup of water on a rolling cart. Position the cart so that it will hit a solid surface like a wall then give the cart a good push, i.e. apply force. Try it a few times with different amounts of force (and surfaces if necessary) until you see the following. Talk about why it doesn't work this way if it doesn't on your first tries[K].

- Initially, the cup and water will slide back.
- Then the cup moves in the same direction as the cart and the water does as well.
- The cart hits the wall and stops. The water and then the cup don't stop right with the cart but instead keep moving forward until they too hit something (like the wall or floor).

EXPLAIN: To change its state of motion, an unbalanced, external force must act on an object.

The plastic bottles remain in place because the force is only applied to the paper. If you were a little clumsy in pulling out the bill, you may have made a big mess because any up and down movement could end up transferring force to the bottles. The top one would topple over, which is change in speed & direction, meaning it was accelerating. FYI - It is important to use paper money because bills are made with water resistant materials so stay intact even when wet.

If you can video tape the pushing of your scooter, this is what you'd see.

- Right when you push, the scooter is the only thing moving. For an instant, the water sits still inside the cup and the cup sits still in space. This is because the force of your push wasn't applied to them so they keep sitting still. Their state of motion (velocity of zero) doesn't change.
- After a fraction of a second however, friction between the cup and scooter grows so its larger than the force of inertia keeping it still. The cup begins to move forward, pushing the water along.
- The wall applies a larger force in the opposite direction than you did in the forward direction so the scooter stops (Newton's 2nd law says an object will accelerate in the direction of the greater force). The cup and water however keep moving forward. Ultimately the floor or wall stops them.

Imagine NASCAR drivers inside cars. Their seat is like the cup and their bodies are like the water. When the car takes off, there is a brief moment when their bodies are still standing still...it is only when the seat and seatbelt transfer the force of movement to their bodies that they also begin to move. This is even more pronounced in drag racing cars that are designed for huge acceleration. NASCAR cars should only start accelerating from zero velocity a hand-full of times over a race that lasts hours.

This transfer of force is even more critical when the car stops suddenly. If you're not wearing a seatbelt then your body keeps flying forward. In a crash you are stopped only by the dashboard, windshield, hood and/or ground. What's the lesson here? WEAR YOUR SEATBELT!

EXTEND: Check out the activity, *Balanced & Boring*, for more on forces.

Balanced & Boring

Activity on Forces

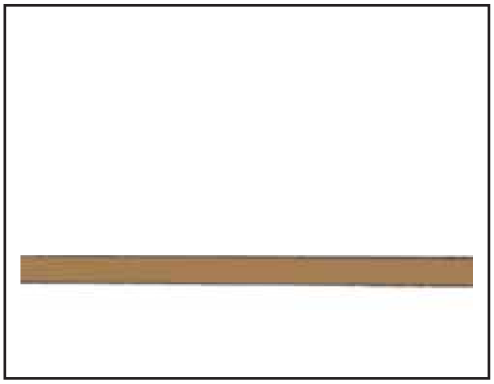
Materials: weigh scale

ESSENTIAL QUESTION: What is an unbalanced and external force?

ENGAGE: Check out the Activity called, *Bodies in Motion*.

EXPLORE: Forces are everywhere, even on your body as you just sit in a kitchen chair or at a desk in school. You just don't think about them because they aren't causing changes in motion....in other words, because they are balanced. Balanced is kind of boring that way.

Balanced vs. Unbalanced. Stand on a weigh scale and see how much you weigh. That weight is the force of gravity working on the mass that is your body. Just because you're not falling doesn't mean gravity isn't applying a force on you. If you're on a ladder and some jokester pulls it away from you, you fall. Just like that ladder step is pushing up on you, the floor is too.



As you stand on this weigh scale, what is the force the floor is exerting on your body?

1. Draw a picture of yourself standing on the weigh scale.
2. Add arrows to make your drawing into a free-body diagram. Label arrows for your weight and gravity with real values[K].

How does your diagram change if someone handed you a 10 pound bag of apples to hold?

External vs. Internal. Sit on top of a towel on a couch or chair. Try to lift the towel out from under you without jumping or pushing on something other than your body. How is it working for you?

EXPLAIN: Matter is anything that has mass. Inertia is a property of matter so it is something that applies to you, me, and most other 'things' we can think of. As Newton described in his first law of motion, inertia is a "resistance to change in motion". For an object to change its motion, it must be acted on by an unbalanced, external force. Not just any old force; it has to be an unbalanced, external force.

In your standing and sitting still, all forces acting on you are balanced. Literally, the ground is pushing up on the floor which is pushing up on your chair or your body. The force up on your body is equal to the force of gravity pulling down on it. If however, someone comes along and pushes you over, your motion changes....abruptly and maybe painfully.

Forces aren't just balanced when sitting still (sitting still means a velocity of zero because there is no change in position). If you roll a ball along the ground in a straight line (without spin which applies a sideways force), then it will not suddenly make a turn. It may make little zigs because the surface isn't perfectly smooth...but between smooth surfaces like hockey pucks on ice (or air hockey pucks on air) the object moves in a straight line because forces acting on it are mostly balanced. We say mostly because there is some friction even between pucks and ice so the puck does eventually stop moving[K].

The unbalancing force has to come from outside because as Newton's 3rd Law of Motion states, for every force there is an equal and opposite force. With every bit of effort you use to pull up on the towel, you're also pushing back down on it. It isn't until you can push on something else that it works.

EXTEND[K]: Draw free-body diagrams of an air hockey puck 1. flying across the table, 2. hitting the wall.

A Resistance to Change

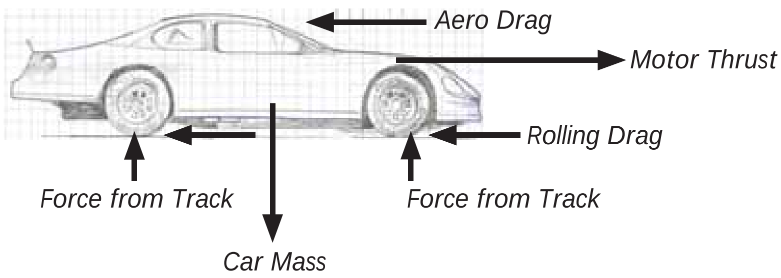
Professor Pi's Math Note & Optional Activity

Materials: rope, bucket, way to connect them so they hang freely, sand or something similar

Newton's 1st Law of Motion...in Newton's Own Words

Every body continues in its state of rest, or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed upon it.

A race car (or any car for that matter) is pushed by its wheels which are turned by the engine. The force from an engine is called motor thrust.



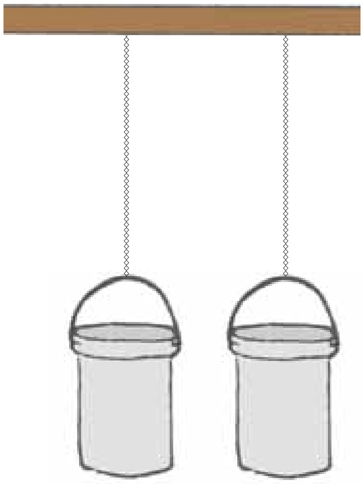
The forward push must overcome the rolling friction of the wheels and the aerodynamic drag of the car's body being rammed through the air. Friction and drag are forces in the opposite direction of travel.

When a car is driving in a straight line, at constant speed, all forces are balanced. Motor thrust forward equals all the drag and friction forces pushing backwards. If the car is changins speed or turning, its forces are not balanced and it is accelerating.

Historical Connection

This statement was published by Newton in 1687 in the Philosophiae naturalis principia mathematica (Mathematical Principles of Natural Philosophy), but the concept of Newton's 1st Law was actually articulated and published earlier by at least Galileo, Kepler, Rene Descartes, and Hooke. This truth is revealed by the fact that motion and rest are separated as two cases. The idea that an object at rest is an inherently different class than an object in motion is Pre-Newtonian. In his other textual and mathematical works, it is clear that Newton understood that an object at rest is simply an object with velocity equal to zero. Rest is a value of velocity rather than a distinct case. Prior to Newton's mathematics, motion with a velocity equal to zero (an object at rest) was thought to be distinctly different than motion with a velocity equal to some real value.

Inertia is a resistance to change in motion. More massive objects have greater inertia and require more force to accelerate them than less massive objects. That is always true so measuring mass is a way to measure inertia.



A trained adult should hang 2 buckets (pendulums) from a ceiling hook or a door frame. They need room to swing in several directions if possible.

Pour sand into one bucket and leave the other empty. If you pull them both back to the same start point and let them go, which one will return to you faster[A]? Stop all motion of both buckets.

Give each one a sharp, quick push. Compare how hard it is to move each.

In mid swing push them in a direction 90 degrees from the path they are traveling. Compare how each one reacts to this change in motion (remember that a change in motion is acceleration).

A. The answer is that they will swing in the same time. The mass of the bob does not affect the period of a pendulum.

Safer Barriers

Activity on Newton's 2nd Law of Motion

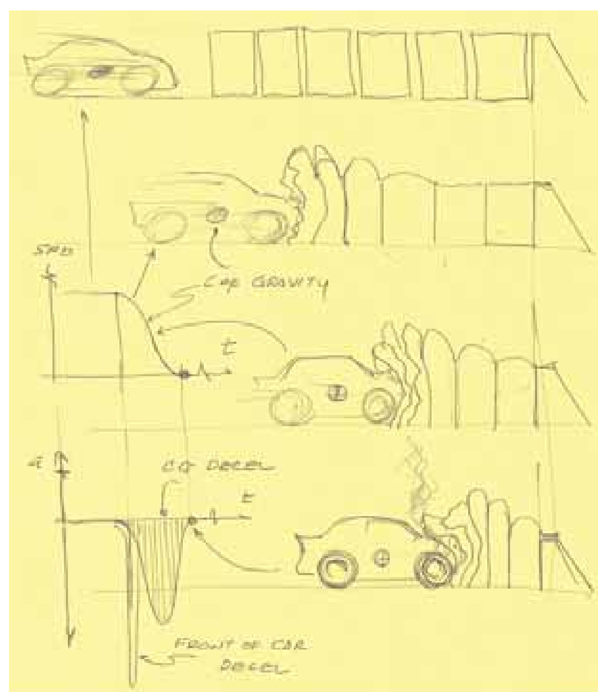
Materials: tape, tape measure, solid object like block of wood, sponge, radio-controlled car or rubber-band launched hot wheels.

ESSENTIAL QUESTION: How does force relate to acceleration?

ENGAGE: The Steel and Foam Energy Reduction (SAFER) barrier is a technology installed primarily on oval race tracks to make accidents safer. Place a 2-3 meter long strip of tape on the floor to form a "track." At the end of the track, place a solid object (a heavy book or piece of wood) that will stop the toy car in a simulated crash. Starting from the same distance on each test, push the car so it hits the wall and watch carefully so you can mark the distance to which the car is repelled. Tape a sponge on the front of the car and repeat the tests. Did the car bounce back as far?

EXPLORE: Brainstorm how to make a safer "crash barrier" that absorbs energy from the crashing car.

1. Make a plan. Describe the barrier you will create and why you predict it will lessen the force exerted on the car when it hits the wall. Come up with a way to make a model of your barrier.
2. Create the model barrier and design a repeatable car crash to test it. Mark a place on the ground where you'll start the car from every time. Use a radio-controlled car or something like a hot wheels car and rubber band launcher to help repeat the same crash over and over.
3. Test the car crash without a safer-barrier and see how far it bounces off the wall. Measure and record the distance the car bounces back when it hits the wall.
   Distance Rebound: ______________________
4. Install your barrier then run at least 3 crash tests; repeat it until you have a repeatable rebound distance. For each test, record how far it bounces off the safer barrier. What's the average?
5. If you think you can improve the barrier, do it and then make a new table to test it again. Remember that a better barrier is one that absorbs more crash energy so the car bounces a smaller distance.



TEST	REBOUND FROM BARRIER
Test #1	
Test #2	
Test #3	
Average	

EXPLAIN[K]: Air bags work on the same principle that SAFER barriers do. That principle is that by lengthening the time over which a person comes to a stop, the peak force back on the person is reduced. Padded dashboards work the same way. This principle works because force and acceleration are proportional.

Crash barriers are designed to lengthen the time of deceleration. Although it may not seem very substantive, the SAFER (Steel and Foam Energy Reducing) barriers doubled the amount of time a car spends in contact with a track wall. That reduces the peak force by half, which can make the difference between a driver with sore muscles and a driver being very severely injured.

We've been talking about how force and acceleration are proportional, but mass is also important. Think about your own experience and answer these questions[K].

1. Is force to accelerate proportional or inversely proportional to an object's mass?
2. For any applied force, is the mass proportional or inversely proportional to its acceleration?

TALK ABOUT IT A LITTLE MORE: First of all, don't get confused. We're talking about crashing, which means stopping very fast. Any change in speed or direction is an acceleration so a stopping car is accelerating just like a car that's taking off or turning. We scientists and engineers say that slowing down is acceleration in the negative direction. Positive acceleration means your speed is increasing while negative acceleration is decreasing speed.

Remember Newton's 1st Law? The driver doesn't stop at exactly the same time as the hood of the car. In a collision there are four impacts: (1) the front of the car stops, (2) then the driver's seat and seat belt stops, (3) then the driver's skeleton stops, and (4) finally the driver's internal organs stop when they hit their skeleton from the inside. It is the last impact that does the real damage.

The critical issue for a driver is how fast he or she accelerates, not the car. And really, the only reason a driver cares about acceleration is because acceleration is proportional to force. Think about it.

- If you're racing your bike, are you going to have to push harder on a short track or a long track? To hit top speed in 50 feet means you have to push harder than if you had 100 feet.
- The opposite is true too. If you have 10 feet to stop don't you have to apply a lot more braking force than if you had 50 feet?
- If you hit the back of your garage going 18 miles per hour doesn't it hurt a lot more than if you're going 5 miles per hour?

All of these examples illustrate that acceleration and force are proportional.

If you design a good crash barrier, there will be a huge difference between the acceleration of breaking parts and the acceleration of the driver. With NASCAR's SAFER barriers, the breaking parts may be at 100 g's while the driver experiences less than 10 g's.

What is a 'g'?

A 'g' is the acceleration due to gravity, 9.8 meters/sec/sec or 32.2 ft/sec/sec. When you're falling, you experience 1 g.

EXTEND[K]: If you change the car mass, but keep the same speed and drive into the same barrier, what will happen? Will it rebound less, the same, more? Add weight to the car and test to find out.

World’s Most Famous Equation

Professor Pi’s Math Note on F = ma

Newton’s 2nd Law of Motion...in Newton’s Own Words

The rate of change of momentum of a body is proportional to the resultant force acting on the body and is in the same direction.

Newton’s second law of motion is written mathematically as Force = mass x acceleration.

To you and me, this means that the force required to accelerate is directly proportional to an object’s mass. Heavier things are harder to accelerate.

Scientists use an understanding of Newton’s 1st, 2nd and 3rd laws to make passengers in cars - race cars and street cars - safer in a collision. Old fashioned cars were very strong and heavy. They could survive a crash with scarcely a dent. The people inside the car, however, were often injured. The force of the collision was transferred to the passengers since it did not get used in deforming the car itself.

Modern cars crumple up more easily. This has the effect of increasing the impact time, thereby reducing forces on the people and the consequent risk of injury is reduced.

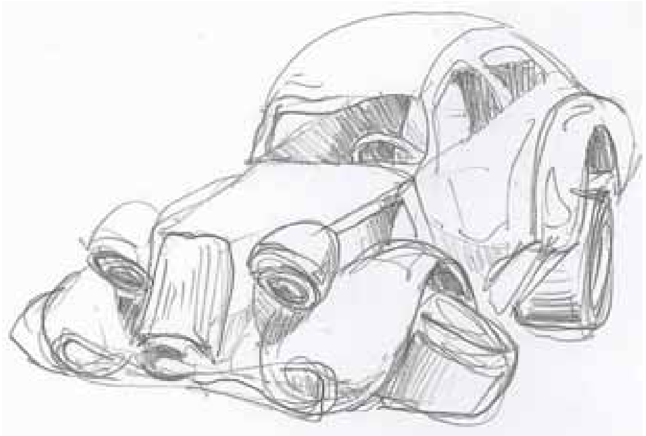
Safety measures enable people to walk away from serious impacts:

- Seat belts restrain passengers and give a little;
- Air bags prevent people from hitting the steering wheel and the dashboard;
- Crumple zones at the front and back of cars fold up, and push heavy parts like the engine underneath.
- Crash barriers on the side of a road absorb impact by giving a little;
- Safety Cages stop passenger compartments being crushed in a roll-over accident;
- Escape lanes on steep hills that allow out of control vehicles to pull off the road. The surfaces consist of shingle and there is an incline. This stops the car. It has to be pulled out by a tow truck, but that’s better than coming off the road and over the side.

DO A LITTLE RESEARCH. When parts fly off the car in a crash, they are carrying kinetic energy (the energy of movement) away from the car and that’s good for the driver. If however, the part has a high mass, it can be dangerous to bystanders. This is why NASCAR requires very strong tethers on some parts of the car. Do an internet search to find out which parts of a NASCAR race car are tethered? Why those?

Avoid a Misconception

What Newton actually wrote was that “the change in the velocity of a body is proportional to the forces acting upon it and inversely proportional to its mass.” Written in mathematical terms, this says: a = F/m. Newton’s statement brings directly to mind the definition of acceleration, a change in velocity. This statement is actually more helpful to students than the common annotated and reorganized statement of most textbooks F = ma.



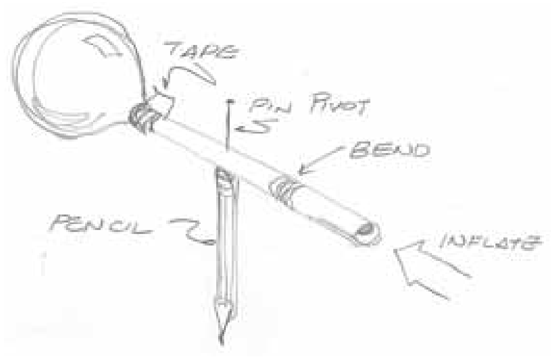
Rockets on Wheels

Activity on Newton's 3rd Law of Motion

Materials: flexible straw, baloon, tape, straight pin, pencil with eraser, scooter or similar, objects (like balls) that you can toss safely.

ESSENTIAL QUESTION: What is an equal and opposite reaction?

ENGAGE: Sit on a rolling chair or a skateboard or other cart with wheels that rolls easily. Have a partner hand you objects (balls work well) one at the time. The balls should be different masses, one as heavy as you can easily toss. Toss a ball from your rolling seat. What happens to the rolling seat? Toss objects of differing masses and compare what happens to the rolling seat. Toss objects at different angles. Compare what happens to the rolling seat. Discuss the actions and the reactions.



EXPLORE: Attach a balloon to the end of a flexible straw with tape. Choose the end that is furthest away from the bend. Push a straight pin through the straw about halfway between the balloon and the bend in the straw and then push the eraser of a pencil into the sharp end of the pin that's now sticking out of the straw.

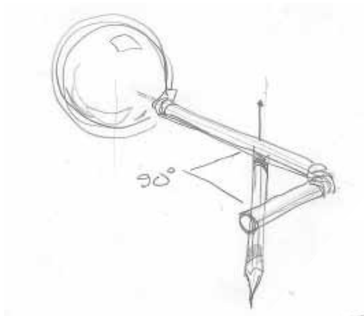
Blow up the balloon and bend your straw to a 90^o angle before allowing the air to escape. What happens?

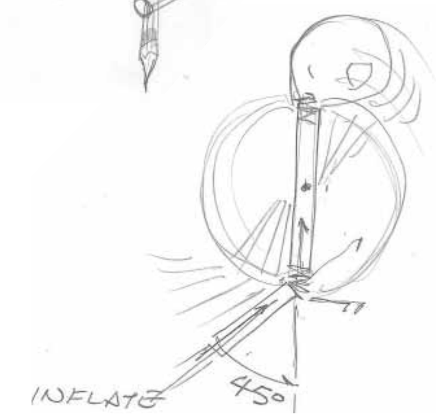
Blow up the balloon and bend your straw to a 45^o angle before allowing the air to escape. What happens?

Blow up the balloon, but leave your straw straight (180^o angle). Release the air in the balloon. What happens?

Remove the pin and hold on to the straw as you blow up the balloon. Release the straw. What happens?

Explain your observations in terms of Newton's 3rd Law.





EXPLAIN: According to Newton's third law, for every action force there is an equal (in size) and opposite (in direction) reaction force. Forces always come in pairs - known as "action-reaction force pairs." Equal and opposite forces are everywhere...to be exact, everywhere there is a force being applied.

- When sitting on the rolling cart, you should find that tossing objects in one direction also pushes you in the other direction. The force to push it forward also pushes you backwards.
- It is also true when you're pushing something heavy. You have to dig your feet into the ground or push backwards against something else.
- The chair you sit in is holding you up just as you are pushing it down.
- The force from a NASCAR Sprint Cup Series car driving forward into a wall is also aimed back from the wall to the car and driver.

EXTEND: Some people refer to race cars as "rockets on wheels". Research vehicles that move like a rocket, as a reaction to a force in the opposite direction. What kind of race cars use this kind of force to make them move? Why are rockets examples of Newton's 3rd law?

The Whole Motion Picture

Professor Pi's Math Note on Collision

Consider what happens when a car collides with a static unbreakable wall (static means unmoving). It all begins with a car traveling at a velocity, V that could be maybe 50 mph or 150 mph depending on your story, and ends with a velocity of zero. The force of going from V to zero is defined by Newton's second law of motion: Force equals mass times acceleration (F=ma). Average acceleration is the rate of change in velocity, (V-0) ÷ t.

$$\text{Average Acceleration} = \frac{(V - 0)}{t}$$

where V is the car's velocity before crashing and t is whatever time it takes the car to come to a stop.

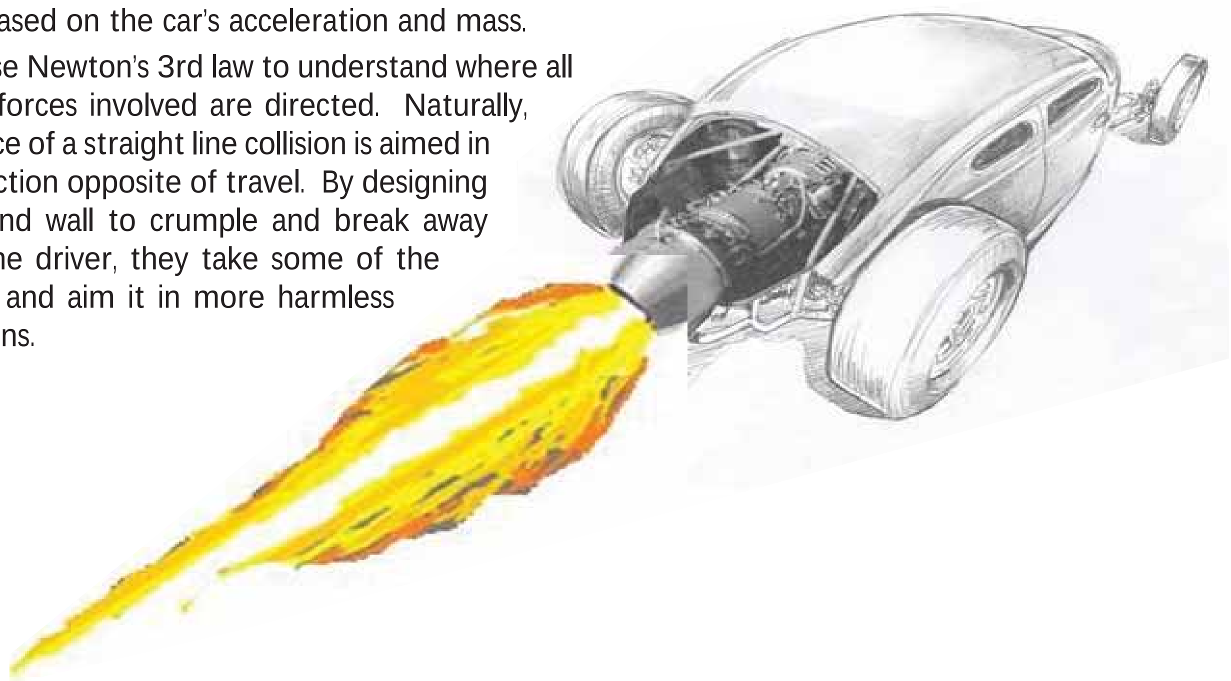
The car exerts this force in the direction of the wall, but the wall (which is static and unbreakable) exerts an equal force back on the car, per Newton's third law of motion. It is this equal force which causes cars to deform during collisions.

Race engineers and engineers of street cars use a hypothetical collision in mind when designing cars and safety mechanisms. Think of a collision in which the car slams into the wall and immediately comes to a stop. This hypothetical crash would be an example of a perfectly inelastic collision meaning that the momentum is conserved, but not the energy of movement. ALL the force would be absorbed by the car because the wall doesn't break or move at all and the full force of the car slamming into the wall has to go somewhere.

These engineers have to understand these forces so they can design ways to keep the full force from transferring to the passengers and avoid the hypothetical situation.

The barriers beside a road and the barriers surrounding a race track are designed using all three of Newton's Laws so that the energy of a collision is used to deform the barrier while making the time of deceleration longer.

1. They use Newton's 1st law to understand that inertia does damage to cars, barriers and bodies because when moving at a high speed they resist the quick stop.
2. They use Newton's 2nd law to calculate the forces involved in a crash based on the car's acceleration and mass.
3. They use Newton's 3rd law to understand where all of the forces involved are directed. Naturally, the force of a straight line collision is aimed in the diection opposite of travel. By designing a car and wall to crumple and break away from the driver, they take some of the energy and aim it in more harmless directions.



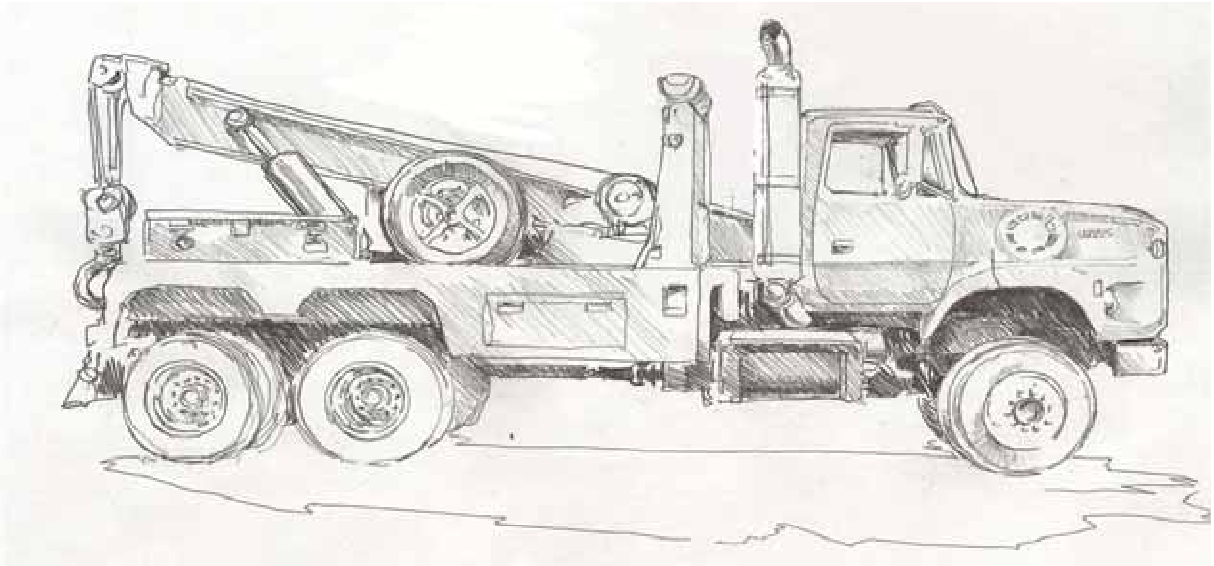
Simplify & Multiply

Activity on Work & Simple Machines

Materials: flexible straw, baloon, tape, straight pin, pencil with eraser, scooter or similar, objects (like balls) that you can toss safely.

ESSENTIAL QUESTION: What are simple machines?

ENGAGE: Can you find examples of these simple machines on this very complex machine? Where are some levers, inclined planes, wedges, wheel and axles, screw threads and pulleys?



EXPLORE: Take a close look at different simple machines, one at a time. Use it to see how each part moves, both the tool and the thing to which you're applying. Answer these for each.

» What is the function of this machine?

» How many moving parts does it have and what do they do?

» How are the moving parts connected to each other?

Gather paper, a pencil and eraser and sketch a diagram for each machine. If you are working with a few people, each drawing will be different because everyone has a unique perspective. Add arrows and written notes to indicate directions of motion for each part, label the elements of machines involved and explain connections. Talk about your diagrams and point out the parts you chose to include. If someone else drew something you omitted, why? Would either of you change your drawing after talking?

Leonardo DaVinci and others recorded their ideas with such accuracy that their imagined machines can be recreated even hundreds of years later. Take a look at the Mythbusters website to see how these modern-day investigators recreated several of DaVinci's original sketches.
http://dsc.discovery.com/fansites/mythbusters/mythbusters.html .

EXPLAIN: A machine is a tool used to make work easier. Simple machines take only one application of force; one push, pull, twist, etc. Compound machines have two or more simple machines working together to make work easier.

EXTEND: Look at the picture of a pit stop on *Professor Pi's Note, There's No Free Lunch*. List things that are done in a pit stop - search the internet for some answers. What simple and compound machines do you see in that image or do you imagine they would have to use?

There is No Free Lunch

Professor Pi's Math Note on Mechanical Advantage

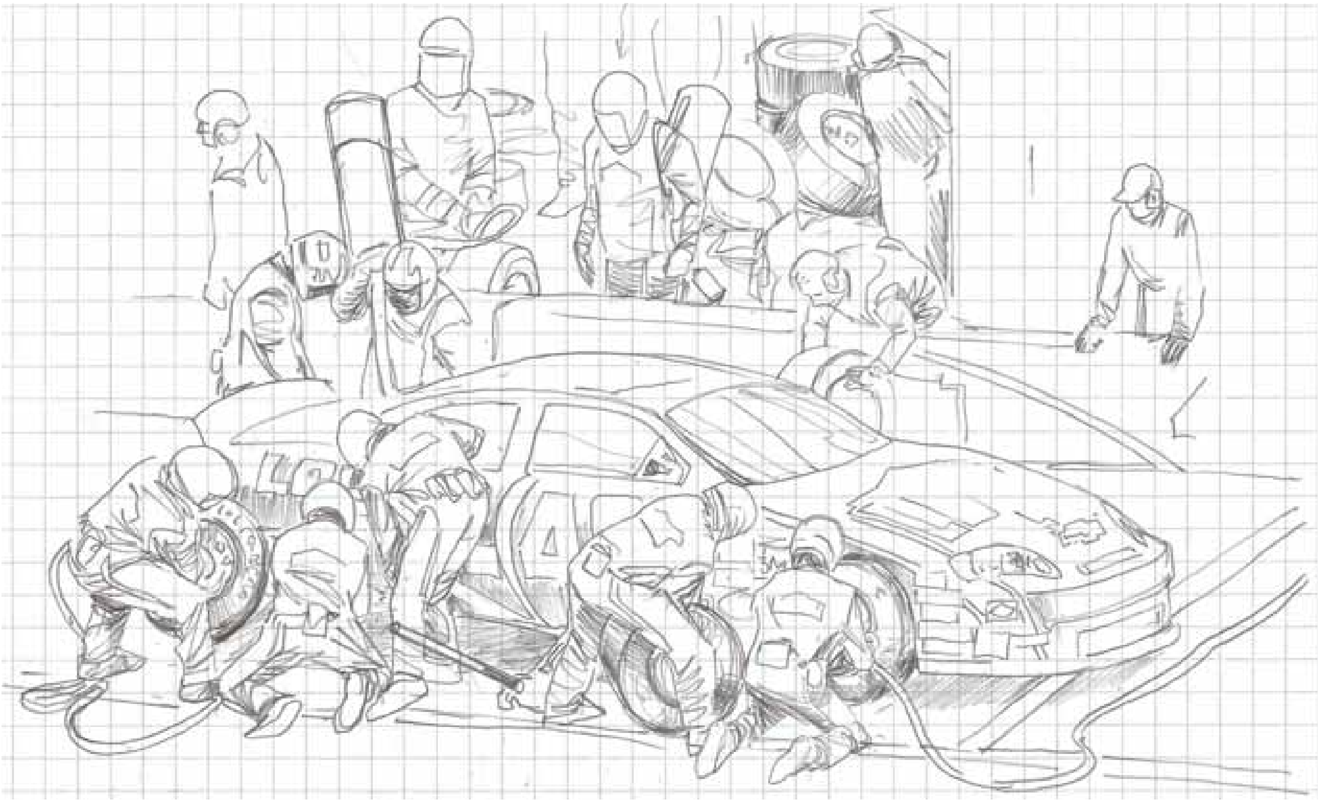
Machines are used to multiply the input force (make it easier to push, pull, twist, etc.) OR multiply motion (go further), but not both. It is only one or the other because even in an ideal frictionless device, the work you put in equals the work you get out (machines don't do work for you).

When riding a bike it might seem like it is doing work for you; however, you're only getting as much work out as you put in. It is a trade-off in distance and effort. When in a low gear, you don't push as hard but you don't go very far for each pedal turn. In a high gear, you have to push hard but you get to go far for each pedal turn. Force and motion are inversely proportional; one goes up and the other goes down (and vice versa).

A lever helps you lift something heavy, but you have to move a long way just to move it a short distance. Think of the hydraulic jack on a NASCAR pit stop. The jackman has to lift from waist-height to almost to the ground while the tires lift only about a foot.

Though the work in = work out, not all of that work is useful to you because in reality, friction in all machines mean that some of the work you put in is lost to waste heat. This means that you have to put IN more work than you actually get OUT. This means that ratio of (output work) to (input work) is always less than 1.00 or less than 100%, and this ratio is used to define the Efficiency of a machine.

The Mechanical Advantage of a machine is the ratio of (distance moved by the input force) to (distance moved by the output force or load); the Mechanical Advantage can also be calculated as the ratio of (load or output force) to (input force). For the jack and all levers, the mechanical advantage is the distance you move divided by the distance the object moves.



Quick Jack & Other Levers

Quick Question on Work & Machines

ESSENTIAL QUESTION: What are levers?

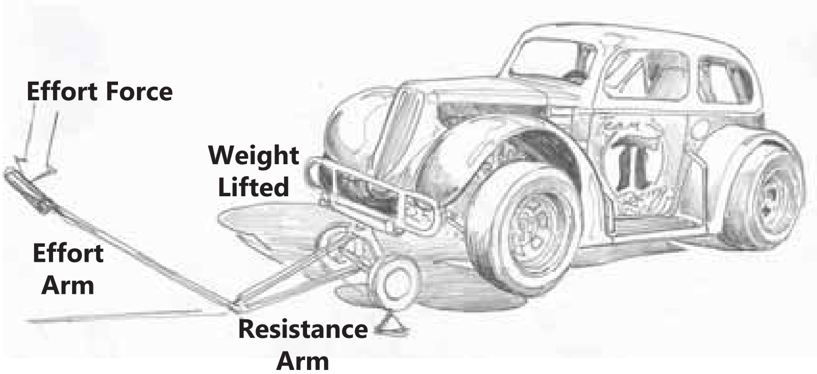
HOW LEVERS WORK

Levers are perhaps the most simple of the simple machines. They predate written history and are still used today by nearly every race team.

Recall that the Mechanical Advantage of a machine is amount by which a machine multiplies force or distance.

To find the Mechanical Advantage of a lever, divide the effort arm length by the resistance arm length.

Effort arm is the one where the most force is applied. In a jack, it is the one you push down. The Resistance arm is the one that doesn't move as far; it multiplies the force but divides the distance.



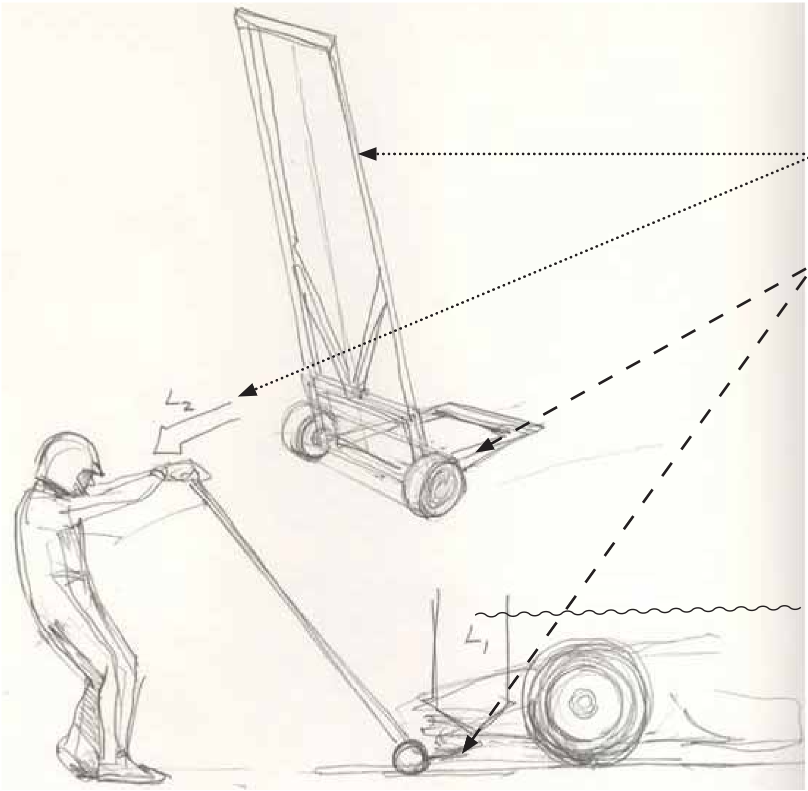
L = Length of Effort arm, F = Force applied to Effort Arm
W = Weight lifted, R = Resistance arm length
MA = Mechanical Advantage

$$MA = L \times F = W \times R$$

Rearrange[K] *to also get:* $MA = L \div R = W \div F$

LEVER PROBLEM[K]

- How much of a mechanical advantage is gained by using a "quick jack" to lift a 1,200 pound car?
- What is the force required to lift half of the 1,200 lb. car?



Effort Arm is 6 feet long

Resistance Arm is 1.5 feet long

Race Car Weighs 1,200 pounds and you only lift half of the car's weight at a time so Resistance Load is 600 lb.

Ramps, Screws & Other Inclined Planes

Quick Question on Mechanical Advantage & Inclined Planes

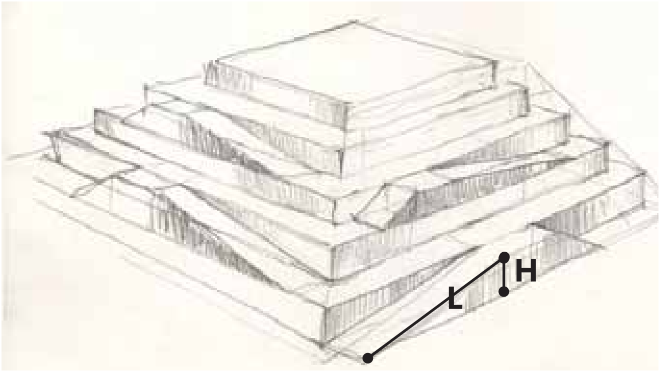
ESSENTIAL QUESTION: How do inclined planes work?

HOW INCLINED PLANES WORK

Inclined planes are thought to have played a pivotal role in the construction of the Pyramids, dating back more than 5000 years. This tool is still in widespread use today. Examples include:

- Hiking trails that wind around and up a hill
- Screws are inclined planes wrapped around center shaft
- Ramps at the back of big trucks

To find the Mechanical Advantage (MA) of an inclined plan, divide the length by its height.



L = Length traveled, H = Resulting height change
F = Effort Force, W = Weight of Load

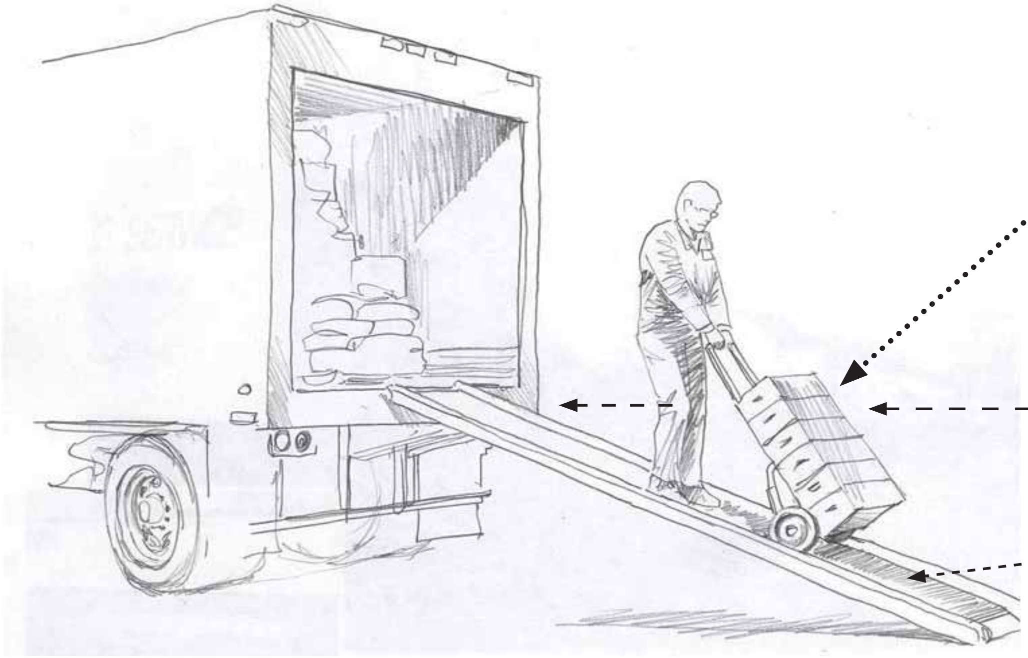
MA = L x F = H x W

Rearrange to also get: MA = L ÷ H = W ÷ F

INCLINED PLANE PROBLEM[K]

Race Teams carry heavy toolboxes into and out of haulers, drive the car into and out of haulers. The cars don't just sit on the floor of the truck, they are actually lifted to a platform near the roof of the truck. How else might inclined planes be used by NASCAR teams to make their work easier?

1. What is the height of the inclined plane?
2. What is the length of the inclined plane?
3. What is the mechanical advantage of the inclined plane?
4. How much effort force would be needed to push the dolly back up the ramp?



Load Carried, W = 60 lb.

Ramp Height, H = 3 ft.

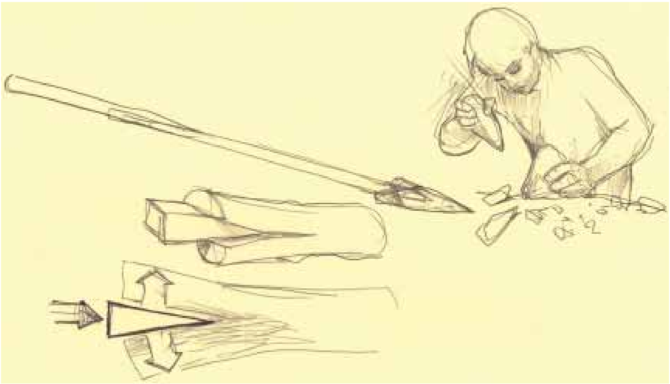
Ramp Length, L = 10 ft.

The Wedge Issue

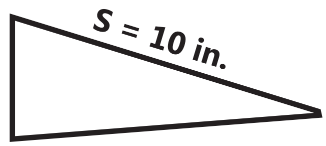
Quick Illustration of Mechanical Advantage & Wedges

Materials: wedge-shaped door stop

ESSENTIAL QUESTION: How do wedges work?



The mechanical advantage of a wedge can be found by dividing the length of slope (S) by the thickness (T) of the big end. The two slopes of a wedge are not always the same; you can use the slope from either side.



As an example, assume that the length of the slope is 10 inches and the thickness is 4 inches. The mechanical advantage is equal to 10:4 = 10÷4 = 2.5 = 2 ½.

HOW WEDGES WORK

A wedge is a piece of wood or metal that is thick at one end and sloping to a thin edge at the other. A wedge is a type of inclined plane, which is another one of the six simple machines. Often a wedge is made of two inclined planes put back to back. Most wedges are used for cutting.

American Indians fashioned stones into cutting edges called arrow heads. They used these arrow heads for knives, spears, axes, and arrows.

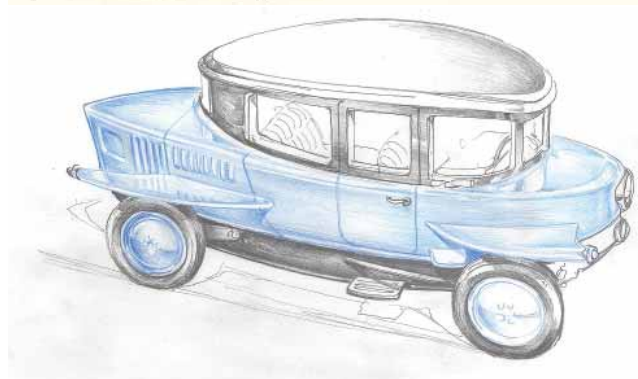
Just like wedges are easier to push through a wooden block, aerodynamic car designs are easier to push through the air than boxy ones.

WEDGES PROBLEM[K]

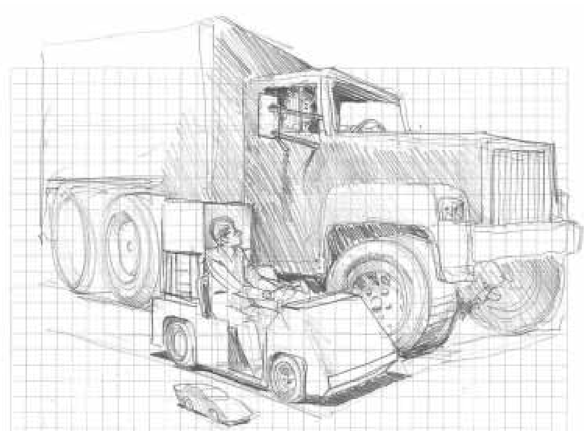
Hold a door shut while someone else tries to shut it (be careful not to actually shut it on anyone or anything). Unless the 'holder' is mush bigger or stronger, you'll find it is very hard to keep open.

After at least one failed attempt to hold the door open, insert a wedge-shaped door-stop. Discuss the difference in how well it works.

What is the Mechanical Advantage of the wedge if the length of the wedge's inclined plane is 10 inches and the height of the wide end is 2 inches?



Wedge shaped cars (above) slice through the air more easily than boxy ones (below)

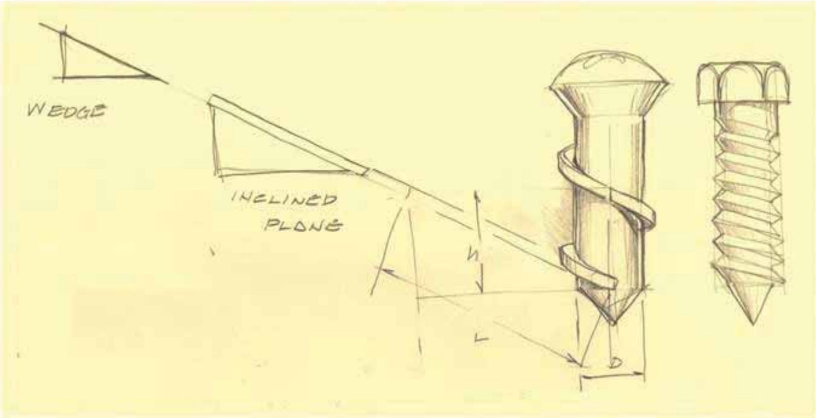


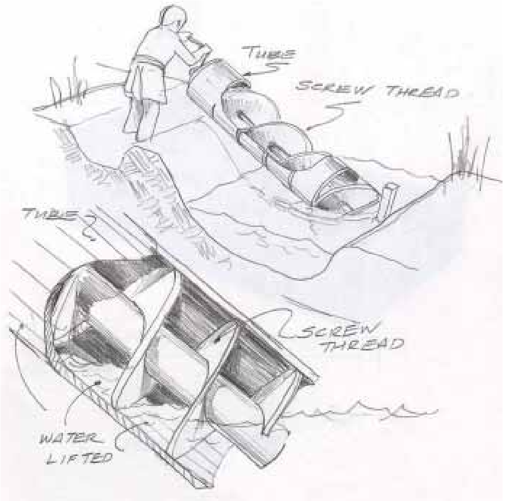
Screwed Up

Quick Activity on Mechanical Advantage & Screws

Materials: paper, pencil, ruler, scissors ,tape, screw, screw driver, something to screw into

ESSENTIAL QUESTION: How do screws work?





HOW SCREWS WORK

A screw is an inclined plane wrapped around a cylinder. As you turn a screw, the object its boring into moves up or down along the threads or the screw itself moves into the material along its threads.

Screws are very useful to holds things together. For example, oil industry workers use small screws to hold things like pens, boxes, motors, and platforms together.

Screws are also useful as wedges to break things. The same oil rig workers have machines with enormous screw-shaped diggers called augers they use to break up the ground.

EXPLORE ACTIVITY[K]:

There are thousands of screws in a NASCAR car and in any street car. List 10 places (ex. holding motor to frame). Look around and list screws that are in the room you're in now, even if you can't see them.

Actually use a screw driver (or your hand to finger tighten) to turn a screw into something. Watch how it, the material or both move along the threads.

Place a piece of paper so that the longest side is at the bottom (landscape). Lay a pencil along the left edge of the paper with the eraser at the bottom left corner of the paper and the point is 'up'. Use a ruler to make a line from the point of the pencil to the bottom right hand corner of the paper. Cut along the line and discard the top part of the paper. Roll the paper around the pencil and tape the end.

Answer these Questions:

1. What simple machine des the flat piece of paper look like?
2. What happens to the paper edge when you wrap it?
3. How is this object like a screw?
4. Where is the inclined plane on a screw?
5. Think about how you use a normal inclined plane and a screw. What is the main difference?

Pulleys

Quick Question on Mechanical Advantage & Pulleys

ESSENTIAL QUESTION: How do pulleys work?

HOW PULLEYS WORK

A pulley is one of the six amazing simple machines and at its simplest, is a rope wrapped around a wheel. Pulleys are used to lift objects and to set objects down.

There are many types of pulleys including fixed pulleys, moveable pulleys, and pulley systems. Depending on which type it is, a pulley can change the direction or size of the effort force.

Using a single pulley like the one shown to the right, you can change the direction of your applied force relative to a load being moved; meaning if you are pulling down the object is lifting up. In this example, you aren't changing the force applied (actually you're losing some due to friction), but changing direction like this is pretty helpful.

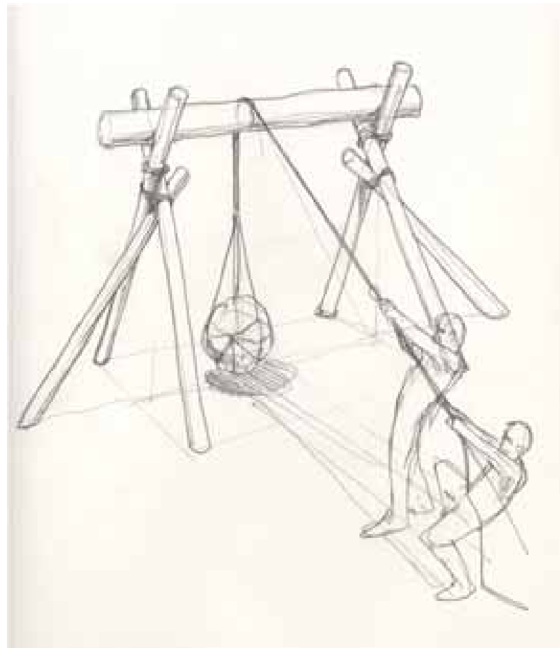
Multiple pulleys can also offer significant mechanical advantage (MA) by multiplying the force you apply or distance of your pull. Like MA for all simple machines, it is equal to the ratio of weight lifted to the force of your pull. MA is also equal to the ratio of distance you pull to the distance the object moves.

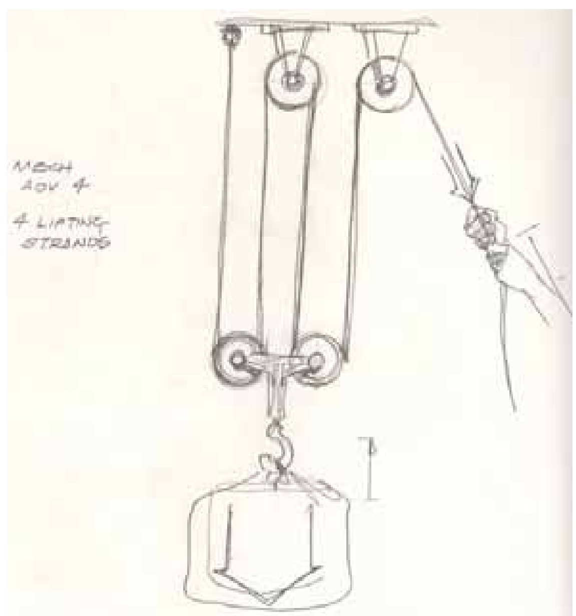
For moveable pulleys like the one shown in the right, bottom picture, you count the number of ropes that support the moveable pulley; count each end of the rope as a separate rope.

PULLEY PROBLEM[K]

What is the mechanical advantage of the moveable pulley in the bottom, right diagram?

If the Load is 100 pounds, what effort is required to lift the load using this configuration?





Pull Force x Pull Distance = Object Weight x Lift Distance

MA = Object Weight ÷ Pull Force

MA = Pull Distance ÷ Lift Distance

Wheel & Axle

Quick Activity on Wheels & Axles

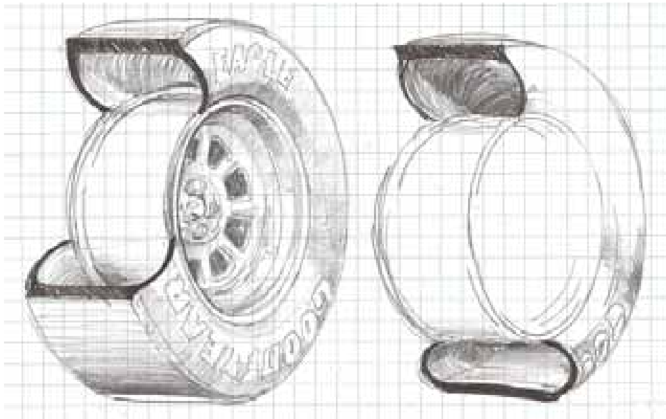
Materials: string, heavy book, pencils

ESSENTIAL QUESTION: How do wheels & axles work?

HOW WHEELS AND AXLES WORK

A wheel and axle is a lever that rotates in a circle around a center point or fulcrum.

The larger wheel (or outside) rotates around the smaller wheel (axle). Wheels can also have a solid shaft with the center core as the axle such as a screwdriver, drill bit or log in a log rolling contest.



One of the most common wheel and axles is something that most people use everyday: the tire of a car or truck.

Where else in a car would you see a wheel and axle? Do you see any in the room around you?

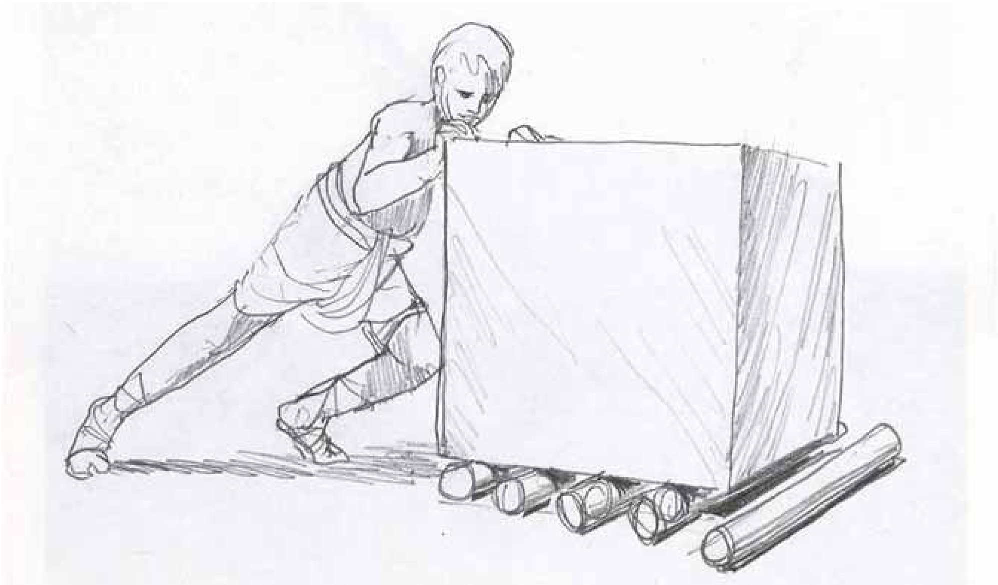
QUICK WHEEL AND AXLE ACTIVITY[K]

Try pulling someone or something around on a chair without wheels, like a kitchen chair. Then try again in a chair with wheels, like an office chair. Which was easier?

Now try moving an object the way the ancients used to do.

1. Tie the string around a heavy book and drag it across a surface like a counter top or kitchen table.
2. Next, place several pencils under the book then again use the string to pull the book so that the pencils roll.
3. Finally, put the book back on the pencils but pull it along the body of the pencils so they don't roll.

Which method requires less force? Why?



Answer Key & Discussion

An endnote, K, in the activity or Pi Note signifies an entry in this section

Measurement 9-Ball, Engage: The best way to measure the depth of a piece of paper is to take a pile of paper, count the sheets, measure the height of that stack and then divide the height by the number of sheets. This is a common way to measure things that are very small - it is an average. The best unit of measure for a single sheet is a millimeter (commonly 0.1 mm or 3.94 mil, a mil is 0.001 inch) and for 10,000 is 1 meter or 3.28 feet.

Pi in the Sky, Explore: Pi is symbolized with the greek letter, pi (π). It is the ratio of a circle's circumference ÷ diameter and always equal for a perfect circle. Pi is an infinite number meaning that the decimal points go on and on and on without repeating. To 50 decimal places, π = 3.14159265358979323846264338327950288419716939937510... When you calculate Pi, your numbers will not always be the same because circles are not always perfect and because your measurements are subject to error. There may be a slight wrinkle in your tape measure or you can't get a measurement that's any more precise than 0.1 inch.

Move It!, Engage: Displacement is your change in position. If you started at d = 0 (the wall) and at the end of all your moving around are back at the wall, your displacement is zero. If after all of your moving around you're 5 feet from the wall then your displacement is 5 feet even if you walked all over the room before landing there.

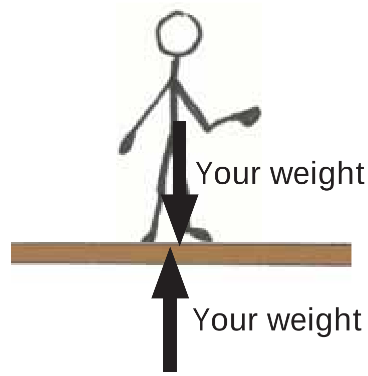
Move It!, Extend: Track speed is 180 mph, track is 1.5 miles long, 334 laps; 334 laps x 1.5 miles / lap = 501 miles, 501 miles / 180 mph = 2.783 hours. The net velocity is nominally zero if the car begins and finishes at the same place. If you're being clever, you might note that some cars may begin 100 feet away from the finish line and their velocity is therefore 501 miles + 100 feet divided by 2.783 hours. You do the conversions and figure it out.

NASCAR Numbers Pi Note: Where are you? Really try to define it well. Pick a reference point and describe where you are in reference to that thing. It gets really difficult when talking to someone who doesn't know where you are AT ALL...Try describing your position from a central and world-famous landmark.

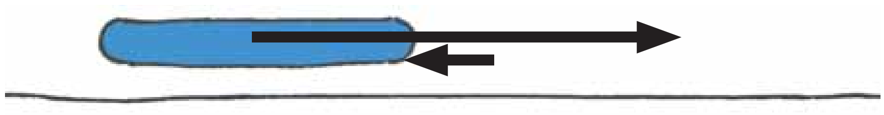
Falling Faster!, Extend: The patterns in data from rolling marbles should be the same though the actual numbers aren't. This is because gravity acts on all objects exactly the same way. It doesn't matter if they are light, heavy, big or small. What makes the numbers change is friction or drag; there is more friction in a rolling toy car than a rolling marble. There is more air drag on a feather and air than there is on a falling piano (you know...like in cartoons).

Bodies in Motion, Explore: The cup might fly off the back right away if you push the scooter too fast - force of friction isn't enough to keep it on board. The cup might not move at all - friction is stronger than the desire to stand still so it moves right along with the scooter the whole time. The cup doesn't fly forward - too much friction keeping it on the cart.

Balanced is Boring, Explore: The arrows are aimed at your center of gravity. That is a point that can represent all of your weight. The floor is exerting an upward force on your body that is equal to your weight. The arrows should be equal in length and opposite in direction.



Balanced is Boring, Extend: Air hockey free body. The forward thrust is much bigger than the friction force pushing it in the backwards direction.



Safer Barriers, Explain: Force and mass are proportional. It takes a higher force to accelerate a bigger mass. Because both increase together, they are proportional. Now...mass and acceleration are inversely proportional. If you apply a force, a larger mass will accelerate less. If you are pushing a couch as hard as you can (your maximum force!), then a lighter couch will start moving more quickly than a heavy couch; higher mass, lower acceleration.

Safer Barriers, Extend: An object with higher mass (heavier) will have more momentum and so the force of collision is higher. The higher mass also means it takes more force to move it. Test this one to see how the balance works out.

Quick Jack & Other Levers: Car = 1,200 lbs so Resistance Weight is 600 lbs. Effort arm = 6 ft., Resistance arm = 1.5 ft.

MA = L x F = W x R = (Effort Arm Length) x (Force) = (Resistance Arm Length) x (Resistance Weight)

MA = 6 feet x F = 1.5 feet x 600 lb;

Rearrange to solve for Force, F: F = (1.5 feet x 600 lb) ÷ 6 feet = 150 lb.

When we say rearrange, all that we're doing is dividing both sides by the same number. For example, if you are comparing length of Charlotte Motor Speedway to the length of Las Vegas Motor Speedway, the equation is 1.5 miles = 1.5 miles. They are the same length. If I divide both sides by 2, the equation is still equal: (1.5 ÷ 2) = (1.5 ÷ 2); 0.75 miles = 0.75 miles.

You're doing the same thing when rearranging equations. To get F on one side of the equation alone (which you need to do because you are trying to find the force to answer this question), divide both sides by L: (L x F) ÷ L = (W x R) ÷ L. Because L d L is 1 (any number divided by itself is 1), you get F on one side alone, L = (W x R ÷ L).

Ramps, Screws & Other Inclined Planes:

1. What is the height of the inclined plane?   3 feet
2. What is the length of the inclined plane? 10 feet
3. What is the mechanical advantage of the inclined plane? MA = 10 ft ÷ 3 ft = 3 ⅓ = 3.33
4. How much effort force would be needed to push the dolly back up the ramp?
   MA = Ramp Length x Effort Force = Ramp Height x Load Weight

The Wedge Issue: Like with inclined planes, the MA is slope length divided by thickness. The example MA is 10 ÷ 2 = 5.

Screwed Up:

1. What happens to the paper edge? The edge looks like a very flat screw
2. What simple machine des the flat piece of paper look like? An inclined plane (or wedge that is an inclined plane)
3. What happens to the paper edge when you wrap it? The edge looks like a very flat screw
4. How is this object like a screw? There is an inclined wrapped around a cylinder - that is a screw.
5. Where is the inclined plane on a screw? The plane in a screw are the threads.
6. Think about how you use a normal inclined plane and a screw.   What is the main difference? You move a screw in a circle to raise and lower

Pulleys: MA is equal to the number of ropes, 4 (yes, the answer on the figure is correct). That means if the object weighs 100 lbs then you have to apply 100 ÷ 4 lbs of weight, or 25 lbs with each pull.

Wheel and Axle: In both cases, using a wheel requires less force to move because there is less friction associated with the rolling wheel than dragging without it. If you are to try pulling a wheel sideways...so it doesn't roll...you'll find it isn't helpful at all.