DESIGN A BOBSLED

Description:
Students explore the effects of gravity, friction and air resistance upon acceleration when they design their own bobsleds.

Grade Levels: 3-8

Educational Outcomes:
1) Students will demonstrate their knowledge of Potential and Kinetic Energy.
2) Students will apply their knowledge of friction, drag, mass and gravity to the design of their bobsleds.
3) Students will gain an understanding (and older students will apply their knowledge) of the concepts of aerodynamics, acceleration, velocity, and terminal velocity.
4) Students will get a first-hand experience of the design process that scientists and engineers undergo.

Estimated Time: 3 class sessions (30-45 minutes each)

California Science Standards Connections:

Grade 3 - Physical Science:
Energy and matter have multiple forms and can be changed from one form to another.
Grade 6 - Physical Science:
Students know energy can be carried from one place to another by heat flow or by waves, including water, light and sound waves, or by moving objects.
Grade 8 - Physical Science:
1. The velocity of an object is the rate of change of its position.
2. Unbalanced forces cause changes in velocity.

All Grades: Investigation and Experimentation: Scientific progress is made by asking meaningful questions and conducting careful investigations. As a basis for understanding this concept and addressing the content in the other three strands, students should develop their own questions and perform investigations.

The Tech Museum Connections:
Life Tech: Bobsled simulator; Innovation: Virtual Design – Design a Bike, Design & Ride a Rollercoaster; Life Tech: Beyond our Limits – Human-Powered Vehicles; Big Ball Machine – energy and motion, transfer of energy; Imagination Playground

Materials And Set-Up (Per Team Of 2-3):

Plastic drinking straws
Craft sticks
Wooden skewers
Toothpicks
Paper clips
Twist ties
Rubber bands
Pipe cleaners
Masking tape
Scissors
Stiff recycled paper (i.e. barcode cards, brochures)

Testing materials-
Stopwatch
Scale
Rain gutters (race track)
Wooden block (to brace the rain gutters)

Please note: This activity was initially developed to be a floor activity for guests of The Tech Museum. It has been modified for classroom use and is a good example of an introductory level design challenge.

Teacher Notes:

Classroom teachers can break up this lesson into 2 or 3 separate days (based on your teaching schedule). We suggest that students have one class period to design, test and discuss their results. A second class period can then be used to receive direct instruction about friction, aerodynamics and terminal velocity before the 2nd Design Challenge (redesign). An additional day may be needed to complete the time trials and final discussion.

Please note: You may need to tailor this lesson to fit the age and experience levels of your students.

A. DESIGN CHALLENGE

Challenge

Design and build a bobsled using the provided materials to race down the rain gutter track.

Constraints

- Each bobsled must weigh 8 grams or less.
- Bobsleds must be able to fit behind the black line on the racetrack.

Testing

Turn the scale on and wait for the display to read "0g." If it reads anything else, press the tare button to make it return to "0g." Place the bobsled on the scale. If the weight is 8g or less, proceed with testing. If it is more than 8g, the designer must go back and modify their design. The bobsled is placed behind the black line on the racetrack. The designer lets go of the bobsled without pushing when the timekeeper says, "Go!" The final time and weight is recorded on the white board.

DC Demonstration and Reflection:

Demonstration: Have students demonstrate their bobsled designs.

Reflection: Have each group of students explain their design strategy and how their bobsled uses energy, forces, and motion to complete the track. Instructor should ask leading questions to get at the science behind the designs.

Teaching Points to guide Reflection Questions:

- ❑ Potential Energy is stored Energy that can be either gravitational (gravity) or elastic (rubber bands, springs...).
- ❑ Kinetic Energy is Energy in motion.
- ❑ Thermal Energy is Energy of temperature.

Questions to encourage Teaching Points:

- When the bobsled reaches the bottom of the track and stops, does it have potential energy? Does it have kinetic energy? *(The answer is no to both questions. The energy has been transformed to thermal energy, which dissipates very quickly.)*
- What if the bobsled is halfway down the track? *(Of course it changes with the situation, but about half of its energy is potential and half is kinetic. Some energy will have become thermal from friction with the track.)*
- What would happen if you made your sled heavier? Would your sled go faster if a lot of your sled were touching the track or a little? Is there a different shape for your sled that would produce a faster time?
- *Ask about specific aspects of their design as well.* Why did you choose to use a (paper clip, toothpick etc.)? What does the (red piece, pointy part etc.) do?

B. SCIENCE DEMONSTRATIONS & DISCUSSION

1. Friction:

When things rub against each other, they generate friction. Materials that slide down the track more easily have less friction, less energy is lost, and so the track time is faster.

Mini-demo ideas:

- Have students rub their hands together. Do they feel the heat? That is the energy from the movement of their hands being converted to thermal energy (i.e. heat) through friction. Potential energy that becomes heat cannot become motion. Low friction means less energy is lost to heat, leaving more energy for motion, meaning the bobsled goes faster.

Teacher Notes:

Potential Energy: Energy that is stored. Placing the bobsled high up on the track gives it gravitational potential energy. One way to think of it is that something with potential energy has the capability to do something. For example, a bobsled at the top of a track can slide down the track because it has potential energy. A bobsled at the bottom of a track cannot slide up the track because its potential energy has been changed to kinetic and then thermal energy. Another example, a stretched rubber band can fly across the room, a relaxed rubber band cannot.

Kinetic Energy: Energy of motion. When the bobsled is released at the top of the track, it starts to slide down: potential energy is converted into kinetic energy. One way to think of this is something with kinetic energy is moving. For example, as the bobsled slides down the track, it has kinetic energy. Or, as the rubber band flies across the room it has kinetic energy.

Thermal Energy: Energy of temperature. We have all made heat by lighting a fire or rubbing our hands together. You can also make things cold by putting it in ice. These are all forms of thermal energy. Thermal energy is unique in that the energy will dissipate, meaning when it is not transformed into another form of energy it combines with the surrounding environment. As it combines, it feels to us like it is disappearing.

- Get a paperclip and a rubber band. Ask the designer which one they think will go fast down the track. Drop the paperclip in one track and the rubber band in the other. The paperclip will slide down the track while the rubber band will stick at the top. Which one has higher friction? *The rubber band.* Things with more friction are "stickier." Kids seem to have an innate understanding that sticky things don't move well.

2. Aerodynamics:

Air resistance, or air friction. When something moves through air, the air molecules rub against the object and create air friction. Friction slows an object down (see the friction section). Air friction is also called drag. The larger the area hitting the air (this is the surface area perpendicular to the direction of motion) the greater the number of air molecules hitting the object at any moment in time, and the more friction is created. More friction means the object slows down more. This is why a parachute works.

Mini-demo idea:

- Get two pieces of paper. Reduce the surface area of one piece by crumpling it up. Drop the two pieces of paper. The crumpled paper will hit the ground first. Gravity accelerates the two objects towards the earth at the same rate. The crumpled paper goes faster because there is a smaller surface for the air to hit, which means less air friction, which means it loses less speed.

The other factor that affects air resistance is the object's velocity. If an object can pass through more air space in a given amount of time, it will collide with more air molecules than the same object with a slower velocity. The more air molecules it hits, the more air friction is created and the more speed is lost.

3. Terminal Velocity:

Acceleration due to gravity = Deceleration due to air resistance. As an object falls it will continue to speed up. As it speeds up the force due to air resistance will increase. That force is accelerating the object in the opposite direction of its movement, or causing it to decelerate. When the force of air resistance matches the force of gravity, the object is being accelerated and decelerated at the same rate. That means there is no acceleration at all. It doesn't mean the object stops falling. It just stops falling faster.

So how does this all go together to affect our bobsleds?

We know:

* We want our bobsled to accelerate as long as possible so it reaches a high speed.
* Gravity will speed the bobsled up. Air resistance and friction will slow it down.
* Eventually, gravity will balance air resistance and friction and stop acceleration. This will be your terminal velocity. The bobsled cannot go faster than this.
* We want to delay reaching terminal velocity as much as possible so the bobsled accelerates as long as possible.
* A heavier bobsled will create a larger gravitational force (to create the same acceleration).
* It will take more air resistance to counteract the larger force of gravity in a heavy object.
* The more air resistance you need, the faster the object must be going to create it, and the longer the bobsled must accelerate to reach that speed.

This is why we want to add weight to our bobsleds.

Mini-demo ideas:

- Get a stack of paper. The barcode cards work well for this. Rubber band the stack together except for one card. Point out that the bottom of the stack of cards and the single card have the same surface area that will hit the air when they are dropped. Hold the stack of cards and the single card at the same height and drop them. The

Teacher Notes:

Momentum: Mass in motion. An object's momentum is a combination of its mass and its velocity. In the beginning of Raiders of the Lost Ark Indiana Jones runs for his life as a gigantic boulder is rolling towards him. He is not about to try to stop the boulder because he knows it is much too heavy. It has too much momentum so he would never be able to stop it. Now, imagine it is not a boulder but a tennis ball rolling towards Indy at the same speed. Because the tennis ball has so little mass, it has much less momentum than the boulder and Indy could easily turn around and stop the tennis ball.

Velocity: Speed (how fast something is going=distance/time) with a directional component. In physics, it matters which way the bobsled is moving. For our purposes, we will not worry about the direction because all the sleds are going the same direction.

Acceleration: Change in velocity. How fast does something go from a standstill to a specific speed? Or from a specific speed to a standstill (called deceleration)? In automotive design, how fast a car goes from 0 to 60 miles per hour is an important statistic. That is acceleration. The longer something accelerates, the more change in velocity it has. A sports car can go from 0 to 60 mph in about 5 seconds. If you have the same acceleration for 10 seconds, the car will be going 120 mph.

Gravity: This is the force by which the earth pulls things back to it. (Technically, anything with mass has gravity, including an 8 year old. It is just too weak for us to feel its effects.) The gravitational force will always create the same acceleration.

stack of cards will hit the ground first. This is because the stack of cards has more mass so it takes longer to reach a speed that will create enough air resistance to counteract the acceleration due to gravity. If you dropped the single card and the stack in a vacuum they would fall at the same rate. We do not have a vacuum available but we can simulate it by placing the single card on top of the stack. When you do that, they will fall at the same rate.

- Get an empty matchbox and a matchbox full of pennies. Slide them both down the track. The matchboxes have the same profile to affect their aerodynamics. Because the box with the pennies is heavier, it will slide down the track faster.

C. DESIGN CHALLENGE #2:
Challenge:
Redesign your bobsled so that you can decrease your initial run time.

Constraints
- Each bobsled must weigh 8 grams or less.
- Bobsleds must be able to fit behind the black line on the racetrack.

Demonstration and Reflection:
Demonstration: Have students demonstrate their bobsled designs on the track and share the results of their investigation.

Reflection: Each group of students will explain their design strategy and how their bobsled uses energy, forces, and motion to complete the bobsled track. Instructor should ask leading questions to get at the science behind the designs.

Questions to elicit student thinking & understanding:
- How did you change your original design? What affect did this/these change(s) have upon the performance of your bobsled?
- Did you do anything specific to increase the aerodynamics of your bobsled?
- Did you do anything specific to help your bobsled accelerate longer (i.e. decrease friction, delay terminal velocity by adding more weight and increasing aerodynamics)?
- If you had more time what would you add, change, or do differently?

Discussion:
If you were to do this again, how many of you think you could design an even faster bobsled? Discuss how scientists & engineers go through this Design Challenge process daily….learning from their mistakes, reflecting and improving upon what they have already designed.

D. CLEAN UP: REDUCE! RE-USE! RECYCLE!
Only throw away items that cannot be re-used. All items should be returned to the appropriate place.

E. POST ACTIVITIES:
- Change the angle and length of the bobsled track. Investigate the results of increasing potential energy (length and height of hill). How does it effect the acceleration & velocity of the bobsled?
- Participate in The Tech's *Physics of Roller Coasters* lesson, to further explore velocity and acceleration by designing a rollercoaster on which a marble will travel.

RESOURCES
Conceptual Physics by Paul Hewitt. HarperCollins College Publishers, New York, NY. 1993.
Glenbrook South Physics website: http://www.glenbrook.k12.il.us/gbssci/phys/phys.html
Rutgers University Physics Education Resource website: http://www.physics.rutgers.edu/hex/visit/lesson/lesson_index.html
The Physics Classroom tutorial website: http://www.physicsclassroom.com/Default2.html

Glossary & Concepts:

Physics Terms

- Acceleration: The rate at which an object changes its velocity. An object is accelerating if it is changing its velocity, both speeding up or slowing down.
- Air resistance: The friction that acts on something moving through air.
- Elastic Potential Energy: Potential energy due to tension -- either stretch (rubber bands, etc.) or compression (springs, etc.).
- Energy: "Nature's way of keeping score." Measured in joules. Appears in many forms, most of which are ultimately derived from the sun or from radioactivity.
- Force: A push or pull. The force applied to a machine is called work input or effort force.
- Friction: Forces resisting motion between one set of molecules and another due to electrical attraction and repulsion, usually between two solid surfaces; static before motion starts and kinetic during motion.
- Gravitational Potential Energy: Potential energy due to elevated position. Gravitation potential energy = weight x height. Note this only depends on vertical displacement and not the path taken to get it there. This value is always relative to some reference level.
- Inertia: The tendency of matter to remain at rest if at rest, or, if moving, to keep moving in the same direction, unless affected by an outside (or unbalanced) force.
- Kinetic Energy (KE): Energy of motion. KE= ½ mass x velocity^2 = ½ mv^2 Note that small changes in speed can result in large changes of KE (it's speed squared!). Net force x distance = KE. Includes heat, sound, and light (motion of molecules). KE is a scalar quantity; it cannot be canceled.
- Mass: the amount of matter that is contained by an object.
- Mechanical Energy: Energy possessed by an object due to its motion or its stored energy of position. Mechanical energy can be either kinetic energy (energy of motion) or potential energy (stored energy of position).
- Momentum: The quantity of motion of a moving object, equal to the product of its mass and its velocity.
- Potential Energy (PE): Energy of position; energy that is stored and held in readiness. Includes chemical energy, such as fossil fuels, electric batteries, and the food we eat.
- Terminal Velocity: The velocity attained by an object wherein the resistive forces counterbalance the driving forces, so motion is without acceleration.
- Velocity (speed): How fast an object is moving. The distance traveled over time.

Newton's Law of Momentum Conservation:

The amount of momentum remains constant - momentum is neither created nor destroyed, but only changed through the action of **forces.**

Newton's Law of Conservation of Energy:

Energy cannot be created or destroyed; it may be transformed from one form into another, or transferred from one place to another, but the total amount of energy never changes.

Newton's Laws of Motion:

1st Law (Law of Inertia):

An object at rest tends to stay at rest and an object in motion tends to stay in motion with the same speed and in the same direction unless acted upon by an unbalanced force.

2nd Law:

When an unbalanced force acts on a body, it is accelerated in the direction of the force; the magnitude of the acceleration is directly proportional to the force and inversely proportional to the mass of the body… **F=ma**