I. MOTION COMMOTION!:

Inspired by the whimsical drawings of Rube Goldberg, students will leverage their knowledge of forces, work, simple machines and conservation of energy to design and build complex contraptions *to complete a simple task.*

Grade Levels: 4-12

Educational Outcomes:

1) Students will demonstrate their knowledge of Potential and Kinetic Energy.
2) Students will be able to identify and build Simple Machines that will work together to form a Complex Machine.
3) Students will observe and make use of the Mechanical Advantage that Simple Machines provide.
4) Students will demonstrate their knowledge of work, forces, conservation of energy, by designing an overly complex contraption to complete a simple task.

Estimated Time: 1.5 hours

- Introductory Design Challenge Activity: 20 min.
- Basic Science Discussion (Simple Machines): 20 minutes
- Design Challenge:
    - Building – 35 minutes
    - Sharing – 10 minutes
    - Clean-up – 5 minutes

CA Science Standards Connections

Grade 6 - Physical Science:

3a. 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 7- Life Science:

6h. Students know how to compare joints in the body (wrist, shoulder, thigh) with structures used in machines and simple devices (hinge, ball-and-socket, and sliding joints); 6i. Students know how levers confer mechanical advantage and how the application of this principle applies to the musculoskeletal system.

Grade 8- Physical Science: Forces

2a. Students know a force has both direction and magnitude; 2b. Students know when an object is subject to two or more forces at once, the result is the cumulative effect of all the forces; 2c. Students know when the forces on an object are balanced, the motion of the object does not change; 2d. Students know how to identify separately the two or more forces that are acting on a single static object, including gravity, elastic forces due to tension or compression in matter, and friction; 2e. Students know that when the forces on an object are unbalanced, the object will change its velocity (that is, it will speed up, slow down, or change direction); 2f. Students know the greater the mass of an object, the more force is needed to achieve the same rate of change in motion.

Grade 9-12 Physics

1. Newton's laws predict the motion of most objects; 1 b. Students know that when forces are balanced, no acceleration occurs; thus an object continues to move at a constant speed or stays at rest (Newton's first law); 1d. Students know that when one object exerts a force on a second object, the second object always exerts a force of equal magnitude and in the opposite direction (Newton's third law).

2. The laws of conservation of energy and momentum provide a way to predict and describe the movement of objects; 2 g. Students know how to solve problems involving elastic and inelastic collisions in one dimension by

using the principles of conservation of momentum and energy; 2h.* Students know how to solve problems involving conservation of energy in simple systems with various sources of potential energy, such as capacitors and springs.

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 Gallery Connections: 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

II. MOTION COMMOTION!: ADVANCED PREP AND SET-UP

Introductory Design Challenge:

Each team of two to three will have:

- One set of plastic K'nex™ and/or 1 set plastic Tinker Toys™
- A small bell

Student research station

- Mouse Trap™ board game
- Frigits™ construction kit
- Magnetic Gears ™ (optional)
- Book: Rube Goldberg: Inventions
- Book: Gizmos & Gadgets: Creating Science Contraptions That Work (& Knowing Why)
- Various household objects that are simple machines (with labels indicating which simple machines)
- Various K'nex toy creations (optional)

Demonstration Table

- Newton's Cradle

Posters for wall: Law of Conservation of Energy, Newton's Third Law of Motion

Design Challenge:

Each team of two will have:

- One set of plastic K'nex™ and/or 1 set plastic Tinker Toys™
- Small bell

General supplies available to everyone (from long table on side of room):

- Balloons
- Rubber bands
- Paper cups
- Dowels
- Wooden skewers
- Film canisters
- String
- Tape
- Drinking straws
- Pipe cleaners
- Cardboard/heavy paper
- Paper towel rolls
- Toilet paper rolls
- Springs
- Marbles
- Ping pong balls
- Clothespins
- Plastic spoons
- Foam pipe insulation

III. MOTION COMMOTION!: LESSON PLAN

Introduction: Talk about Rube Goldberg and Heath Robinson (UK cartoonist from same era that drew similar contraptions). Show images of Rube Goldberg designs and discuss how his illustrations made simple tasks into incredibly complex, but whimsical, multi-stepped procedures. Introduce students to toys such as Frigits™, Magnetic Gears™, and the board game Mouse Trap™. Discuss the simple machines that are being utilized and the energy transfers that are occurring within the toys. Let students know that they will have an opportunity to research these toys further, to assist them in their own design process.

Mini Design Challenge: MOTION COMMOTION!

Challenge: Design and construct a "Rube Goldberg" style machine (with multiple steps) to ring a bell.

Constraints:

- Your machine must have at least 2 energy transfer (action-reaction) steps.
- Your machine may not have any human energy input except for at the beginning.
- You can only use the materials supplied.
- You can visit the research station at any time to get ideas for your design.
- Each group member must participate in the design, construction, and operation of the contraption.

DC Demonstration and Reflection:

Demonstration: Have students demonstrate their device for the class while at their tables. If students have not completed their device ask them *how the device would have worked.*

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

Force:
A push or pull. The force applied to a machine is called work input or effort force.

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).

Kinetic Energy:
Energy of Motion. Includes heat, sound, and light (motion of molecules).

Potential Energy:
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.

Elastic Potential Energy:
Potential energy due to tension -- either stretch (rubber bands, etc.) or compression (springs, etc.).

Gravitational Potential Energy:
Potential energy stored in an object as a result of its vertical position (i.e., height).

Teaching Points (Conservation of Energy and Momentum content):

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

Questions to encourage teaching points:

- How is the energy stored in your machine? How does energy move in your machine? Does energy transfer from one object to another? If yes, how many times does it do this?
- Can you identify where potential energy is being stored?
- What types of Potential Energy are being demonstrated by your machine design? (PE can be either gravitational or elastic) *Continue to identify the PE and KE of the various* machines *and the form of PE being used.*

Mechanical Advantage of Simple Machines (Discussion, Activities & Demonstrations):

Teaching Points for Mechanical Advantage (Motion & Forces content):

- Simple Machines make work easier by providing a mechanical advantage (the ratio of effort to resistance).
- Simple machines reduce the amount of effort needed to move something, but the trade off is that you move it a greater distance to accomplish the same amount of work.

1. Real World Application Discussion:

- Present a student with a paint can and ask him/her to open it. Ask if a tool would help…(screw driver).
- Present a student with a load of books and ask him/her to move it across the classroom. Ask if a tool would help (cart). Ask what they would need to make it easier to move the load upstairs (elevator or ramp). If elevator is offered ask what they would want to use if there was no elevator (ramp).
- Point out that all the tools mentioned are examples of simple machines (lever, wheel & axel, pulley, inclined plane) and that these tools are provide something called a **mechanical advantage (MA)**, which makes work easier.

Work:
A force acting on an object to move it across a distance. Pushing, pulling, and lifting are common forms of work.

Simple Machines:
Simple tools used to make work easier. These include the pulley, lever and inclined plane. Variations of the most basic simple machines include the screw, wheel and axle, and wedge.

Compound machines:
Two or more simple machines working together to make work easier.

Machine:
A device that lets us do work with less effort by transferring a force.

Mechanical Advantage:
When a machine puts out more force than is put in, the machine is said to have mechanical advantage.

The mechanical advantage can be found by dividing the force of the machine by the force you used on the machine…in other words, dividing the load or resistance by the effort.

2. Lever Activity:

Use rulers with some sort of fulcrum (e.g. erasers, thick markers, film canisters) to create a lever. Move the lever (ruler) along fulcrum to test the MA by trying to lift an object. Notice that when the fulcrum is farther away from the object the workload or force needed to lift the object is greater than when the fulcrum is much closer to it. Note that there is a tradeoff for the extra lifting power, which is the distance, or in this case height, that the object can be lifted.

Questions to encourage teaching points:

- What happens when the fulcrum is directly in the middle of the ruler? Is it easy to move your object?
- Is the force you use equal, greater or less than the weight of the object?
- How about when the fulcrum is closer to your object? Does it get easier or harder to move your object as the ruler moves across the fulcrum (so that the object is closer to the fulcrum)?
- What happens to the distance or height that you can raise your object as the fulcrum is moved closer to the object?
- What happens if you move the fulcrum far away from the workload (object)? Is the force you use equal, greater or less than the weight of the object?
- Is there any mechanical advantage of doing this?
- Can you find any parts of your body that can act like a lever?

(Arms & legs are examples of 3rd class levers—see resource notes)

- For further study – proceed to the nearest playground with a friend or friends to investigate the mechanical advantage provided by a seesaw!

3. Discuss Mouse Trap™ game (Research Station item):

Present the game Mouse Trap™ to students and ask them to first identify all of the energy transfers. Then ask students to identify all of the various Simple Machines that are being utilized (inclined planes, levers, wheel & axels). Ask students if the game utilizes elastic and gravitational potential energy (yes), if so, indicate where. Ask them how the series of simple machines conveying mechanical advantage at each step contribute to accomplishing an overly complex task.

Teacher Notes:

Simple Machines reduce the effort (force) needed to get the job done. However, the **trade-off** is that this is done by moving things a greater distance.

In short, the equation balances out and in the end, the amount of work (force x distance) you do is exactly the same.

Lever trade-off:
By changing the position of the fulcrum, you can gain extra power with less effort, however, you will need to cover more distance to move a load a proportionally shorter distance.

Wheel and Axel trade-off:
The larger the diameter of the wheel, the less effort you will need to turn it, but you will have to move the wheel a greater distance to get the same work done.

Gears are used to:

- Reverse the direction of rotation
- Increase or decrease the speed of rotation
- Move rotational motion to a different axis
- Keep the rotation of two axes synchronized

Design Challenge: MOTION COMMOTION! (2)

Challenge: Design and construct a "Rube Goldberg" style machine (with multiple steps) to ring a bell.

Constraints:

- Your machine must have at least 3 energy transfer (action-reaction) steps.
- Your machine needs to include 3 simple machines (2 unique).
- Your machine may not have any human energy input, except to trigger the chain of events at the beginning.
- You can only use the materials supplied.
- You can visit the research station at any time to get ideas for your design.
- Each group member must participate in the design, construction, and operation of the toy.

E. Demonstration and Reflection:

Demonstration: Have students demonstrate their contraption for the class while at their tables. If students have not completed their device ask them *how the device would have worked.*

Reflection: Each group of students will explain their design strategy and how their device uses energy, forces, and motion. Instructor should ask leading questions to elicit student thinking and understanding.

Questions to elicit student thinking & understanding:

- Did you continue to work on your original design or try something new?
- Which simple machines did you incorporate into your design?
- What mechanical advantage do they provide to the whole machine?
- How does your toy transform potential energy (elastic or gravitational) to kinetic energy?
- Did you do any research to inform your design? How did it help you?
- How could you simplify this overly complex task? How might you make it more complex given more time and materials?
- If you had more time what would you add, change, or do differently?

F. Clean up: **Reduce! Re-use! Recycle!**

Only throw away items that cannot be re-used. All items should be returned to the appropriate place.

G. Pre- and post activities:

- **Post-activity:** Have students research Rube Goldberg and then draw a cartoon sketch of their proposed contraption. (This is a great opportunity for budding cartoonists to shine.) Have students try to build the designs that they created (improvising when necessary).
- **Post-activity:** Hold a Rube Goldberg Machine contest for the class, school or district (using whatever supplies are available to the students). Have them market their designs (create packaging, advertisements, commercials, etc). See the official website: http://www.rube-goldberg.com

  Extension: add a height constraint to the challenge: i.e. students' contraptions should attain a vertical Δ of 10 cm (just an example – height can be determined by teacher.

IV. MOTION COMMOTION! TEACHER NOTES

***Simple Machines Historical Perspective*:** By the first century BC, most fundamental mechanical devices had been invented. Ancient Greeks listed five (wheel & axle, wedge, lever, pulley, and screw). Other things such as gears, chain wheels (e.g. bike chains), and cams were also known, but considered variations of the lever. Apart from the screw, ancient Chinese also invented all these mechanisms. All basic mechanisms were known over 2,000 years ago. Since then, very few new mechanisms have been added to this list. (From the Inventa Book of Mechanisms)

Glossary & Concepts:

Physics Terms

- 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.
- Compound machines: Two or more simple machines working together to make work easier.
- Elastic Potential Energy: Potential energy due to tension -- either stretch (rubber bands, etc.) or compress (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.
- Fulcrum: a lever's pivot point.
- 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.
- Inclined plane: A sloped surface that does work by trading force for distance. This includes ramps, wedges, screws, and scissors/cutters.
- 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. This includes heat, sound, and light (motion of molecules). KE is a scalar quantity; it cannot be canceled.

- Lever: A bar resting on and tending to rotate about a fixed point when force is applied. The lever type is determined by the order of load/fulcrum/force as described below:
  - First class lever: load-fulcrum-force; force & load move in the opposite direction; seesaw. Trades force for distance.
  - Second class lever: force-load-fulcrum; force and load move in same direction; wrenches, wheelbarrows.
  - Third class lever: fulcrum-force-load; force & load move in same direction, but force cannot travel farther than load (no positive mechanical advantage); arms, legs, fishing poles, cranes, and backhoes. Useful for reaching; always sacrifices force for distance.
  - Cantilever: A lever with one end supported and the other end free.
- Machine: a tool used to make work easier. Simple machines are simple tools used to make work easier. Compound machines have two or more simple machines working together to make work easier.
- Machine (more complex definition): A device for multiplying forces or simply changing the direction of forces. Note that machines *cannot* multiply or create work or energy – that goes against the law of conservation of energy! Any machine that multiplies force does so at the expense of distance; any machine that multiplies distance does so at the expense of force.
- Mechanical Advantage: The number of times a machine multiplies the effort force (The mechanical advantage can be found by dividing the force of the machine by the force you used on the machine).
- 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).
- 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.
- Simple Machines: Simple tools used to make work easier. These include the pulley, lever and inclined plane. Variations of the most basic simple machines include the screw, wheel and axle, and wedge.
- Work: A force acting on an object to move it across a distance. Pushing, pulling, and lifting are common forms of work.

- Wheel and Axle: Something round that turns around or with a rod. Does work by trading force for distance. Circumference of wheel is greater than circumference of axle – apply smaller force over large wheel distance to move object. Wheel & axle may or may not turn independently.
  - Gears: Toothed wheels. Mechanical advantage occurs when the two gears are not the same size. If a little gear turns a big gear, the big one turns slower than the small gear, etc.
  - Pulleys: Grooved wheel (to hold rope).
    - *Fixed pulley*: is attached to an anchor. It does not change the amount of force required to perform a task, it only allows you to change the direction in which the force is applied.
    - *Moveable pulley*: is attached directly to the load and lifts with it.
    - *Block and tackle*: A compound machine made of fixed and movable pulleys. Weight is evenly divided between the number of lines that support it. Block=pulleys; tackle=lines/ropes.
  - Hinges: Think of the wheel as the frame attached to the door and the jamb, and the axle is the pin that holds two frames together.

Math Connection - Calculating Mechanical Advantage:
The mechanical advantage can be calculated for the following simple machines by using these formulas:

Lever: MA = length of effort arm / length of resistance arm.
Wheel and Axle: MA = radius of wheel / radius of axle
Inclined Plane: MA = length of slope / height of slope
Pulley: All pulleys have a fixed MA depending on the type. A pulley with one rope (single fixed pulley) has an MA = 1. A pulley with two ropes (single moveable pulley) has a MA = 2. A pulley with 6 ropes (block and tackle) has an MA = 4.

Examples of simple machines in everyday life:
Levers--teeter totter, oar, rake, hoe, bat, pick, fork, screw driver, snow shovel, hammer, bottle opener, light switch, spatula, stapler, crowbar, scissors, car jack, etc.
Screw--different sizes of screws for metal or wood, drill, meat grinder, bolts, nuts, corkscrew, swivel chair, jar lid, etc.

Inclined plane (ramp)--ladder, escalator, hill, roller coaster, stairs, wheelchair ramp, gangplank, dump truck, unloading ramp, parkade (what does this mean?), etc.
Wedge- -paper cutter, scissors, crowbar, chisel, axe, prying tools, can opener, door wedge, pins, needles, nails, etc.
Pulley- -fan belt, elevators, steam shovels, flagpole, clothesline pulleys, derricks, cranes, lifts, pulleys, gears, old-fashioned well, block and tackle, winch, wire stretchers, Venetian blinds, etc.
Wheel and axle--windmill, bicycle, roller skate, vehicles, rolling pin, egg beater, helicopter, old-fashioned telephone dial, fishing reel, record player, tapes, door knob, pencil sharpener, bobbins, fans, casters, etc.

Resources:

- *Conceptual Physics for Parents and Teachers: Mechanics* by Paul Hewitt. Focus Publishing/ R. Pullins Company, Newburyport, MA. 1998.
- *Exploring Energy with Toys* by Beverley A. P. Taylor. Terrific Science Press, Middletown, OH, 1998.
- *Gizmos & Gadgets: Creating Science Contraptions that Work* by Jill Frankel Hauser. Williamson Publishing, charlotte, Vermont. 1999.
- *The Inventa Book of Mechanisms* by Dave Catlin. Valiant Technology Ltd., London, England, U.K., 1995.
- *Rube Goldberg Inventions* by Maynard Frank Wolfe. Simon & Schuster, New York, New York. 2000.
- *Simple Machines* by Fran Whittle and Sarah Lawrence. Raintree Steck-Vaughn Publishers, Austin TX, 1998.
- *Simple Machines Made Simple* by Ralph St. Andre. Teacher Ideas Press, Englewood, CO, 1993.
- Brainpop Simple Machines website: http://www.brainpop.com/tech/simplemachines/
- Center of Science and Industry Simple Machines Web Site http://www.cosi.org/onlineExhibits/simpMach/sm1.html
- Rutgers University Physics Education Resource website: http://www.physics.rutgers.edu/hex/visit/lesson/lesson_index.html
- The Physics Classroom lessons website: http://www.glenbrook.k12.il.us/gbssci/phys/Class/energy/energtoc.html