# Motion Commotion

Design Challenge Learning

The Tech
Museum of Innovation

201 S. Market St.
San Jose, CA 95113
1-408-294-8324
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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. As students iterate through this design challenge, they gain firsthand experience in the design process.

**Grades 3-8**

**Estimated time: 60 minutes**

**Student Outcomes:**

1. Students will be able to create an overly complex device that demonstrates the conservation of energy in order to complete a simple task.
2. Students will be able to identify the simple machines that work together to form a complex machine.
3. Students will be able to observe and make use of the mechanical advantage provided by simple machines.
4. Students will be able to utilize the three step design process to meet an engineering challenge.

**Next Generation Science Standards**

**Grade 3-5:** *Engineering Design* 3-5-ETS1-1, 3-5-ETS1-2, 3-5-ETS1-3
**Grade 3:** *Physical Science* 3-PS2-1, 3- PS3-2
**Grade 4:** *Physical Science* 4-PS3-1, 4-PS3-3, 4-PS3-4
**Grade 5:** *Physical Science* 5-PS2-1
**Grade 6-8:** *Engineering Design* MS-ETS1-1, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4; *Physical Science* MS-PS2-2, MS-PS3-1, MS-PS3-2, MS-PS3-5

**Common Core Language Arts-Speaking and Listening**

**Grade 3:** SL.3.1b-d, SL.3.3, SL.3.4a
**Grade 4:** SL.4.1b-d, SL.4.4a
**Grade 5:** SL.5.1b-d, SL.5.4
**Grade 6:** SL.6.1b-d
**Grade 7:** SL.7.1b-d
**Grade 8:** SL.8.1b-d

**California Science Content**

**Grade 3:** *Physical Science* 1.b-d; *Investigation and Experimentation* 5.a-b, d
**Grade 4:** *Investigation and Experimentation* 6.a, 6.c-d
**Grade 5:** *Investigation and Experimentation* 6.a-c, 6.h
**Grade 6:** *Investigation and Experimentation* 7.a-b, 7.d-e
**Grade 7:** *Investigation and Experimentation* 7.a, 7.c-e
**Grade 8:** *Physical Science* 1.a-e, 2.a-g; *Earth Science* 4.e; *Investigation and Experimentation* 9.a-b

**Vocabulary:**

*Familiarity with these terms and concepts will enhance students' experience in the activity.*

- 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.

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- Elastic Potential Energy: Potential energy due to tension – either stretch (rubber bands, etc.) or compress (sprigs, etc.).
- Energy: The ability to do work. Appears in many forms, all of which are either kinetic or potential.
- Force: A push or pull. An influence on a body or system, causing or tending to cause a change in movement or shape.
- Fulcrum: A lever's pivot point.
- Gravitational Potential Energy: Potential energy due to elevated position. *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. Includes heat, sound, and light (motion of molecules).
- 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 and load move in the opposite direction; seesaw. Trades force for distance.
    - Second class lever: Force-load-fulcrum; force and load move in the same directions; wrenches, wheelbarrows.
    - Third class lever: Fulcrum-force-load; force and load move in the 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 using or applying mechanical energy and having several parts, each with a definite function and together performing a particular task. *Advanced definition: A device for multiplying forces or simply changing the direction of forces. Note that machines cannot multiply or create work or 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.
- 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 smaller 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.

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- Block and tackle: a compound machine made of fixed and moveable pulleys. Weight is evenly divided between the number of lines that support it. Block=pulleys; tackle=lines/ropes.

**Mathematical Connections:**

*Familiarity with these mathematical connections will enhance students' experience in the activity.*

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

**Everyday Simple Machines:**

*Being able to draw connections between simple machines and everyday items will enhance student's experience in the activity.*

- 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: wood or metal screws, drill, meat grinder, bolts, nuts, corkscrew, swivel chair, jar lid, etc.
- Inclined plane: ladder, escalator, hill, roller coaster, stairs, wheelchair ramp, gangplank, dump truck, parkade (multi story parking garage), 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, old-fashioned telephone dial, fishing reel, record player, tapes, door knob, pencil sharpener, bobbins, fans, casters, etc.

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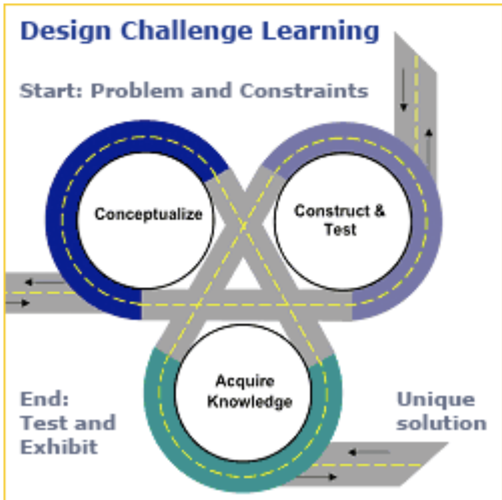
**Resources:**

- Kinetic and Potential Energy Comparison: Powered by Diffen, the website that allows you to compare anything, and includes an overview of kinetic and potential energy. www.diffen.com/difference/Kinetic_Energy_vs_Potential_Energy
- PhET Interactive Simulations: Administered by the University of Colorado Boulder, the website provides a variety of interactive simulations for science and math. It includes simulations dealing with motion, energy, power, and work. There is a simulation that allows students manipulate a ramp in order to discover the forces, energy, and work on household objects through graphs. In 2011, PhET was selected as a Tech Awards Laureate for the Microsoft Education Award. https://phet.colorado.edu
- Newton's Crade: An online interactive animation of Newton's Cradle created by Bryan Heisey and administered by Lock Haven University. www.lhup.edu/~dsimanek/scenario/newton.htm
- Rube Goldberg: The official website for Rube Goldberg providing biographical information on the artist/engineer, his awards, career highlights, history, and legacy. www.rube-goldberg.com
- Heath Robinson: An article by Wired.co.uk on the life and work of Heath Robinson. The article includes a gallery of 21 of his prints and a short documentary introducing the work of Heath Robinson (4:38). It discusses his contributions to today's popular culture including influences seen in the Monty Python and Wallace & Gromit. http://www.wired.co.uk/news/archive/2013-07/29/heath-robinson-deserves-a-museum

**Design Challenge Process:**

*The Design Challenge Process is designed so students reinforce their science, mathematics, social studies, and language arts content knowledge, through an open-ended process that results in an original, team-driven solution. Students are expected to take responsibility for assessing their own progress and incorporate peer feedback as they conceptualize and redesign their projects.*




*The process consists of three interconnected steps:*

**Conceptualize**
- Identify problem, materials, and constraints
- Brainstorm ideas and possible solutions

**Construct and Test**
- Select a solution
- Design and construct
- Prototype
- Redesign or modify
- Retest

**Acquire Knowledge**
- Research
- Share solutions
- Reflect and discuss

*Through the try, fail, learn approach, students develop skills and habits of mind of Silicon Valley innovators: creativity, problem solving, design, collaboration, leadership, risk-taking, perseverance, and learning from failure.*

https://www.thetech.org/educators/design-challenge-learning

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**Materials:**

*Materials can be limiting or inspirational to students! Have a wide variety of materials to promote a diversity of solutions. "Recycled items" are really useful: old mouse pads, wood scraps, boxes, cardboard tubes, strawberry baskets, etc.*

**One Set Per Team of 2 Students:**

- Assorted K'nex™
- Small bell

**Class Supplies to Share:**

- 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

**Directed Instruction:**

- Mouse Trap™ board game
- Frigits™ construction kit
- Various household objects that are simple machines
- Various K'nex™ creations
- Book: Rube Goldberg: Inventions
- Book: Gizmos & Gadgets: Creating science Contraptions that Work (& Knowing Why)
- Book and Set: GoldieBlox™
- Newton's Cradle
- Rulers
- Fulcrum material (large erasers/markers/film canisters)
- Small Weights

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## Lesson Plan:

**Introduction** *(5 minutes)*

1. 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.
2. Introduce students to toys such as Frigits, the board game Mouse Trap, and GoldieBlox. Discuss the simple machines that are being utilized and the energy transfers that are occurring within the toys.
3. Introduce some everyday simple machines and discuss how they create mechanical advantage to make our lives easier.

**Motion Commotion: Part One** *(15 minutes)*

1. Introduce the Challenge: Design and construct a "Rube Goldberg" style machine (with multiple steps) to ring a bell.
2. Introduce the 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.
3. Build: Give students about 10 minutes to build. Instructor should ask open-ended questions to help guide students through the design process, but should also allow students space to tinker.
4. Demonstration: Have students demonstrate their device for the class. If students have not completed their device ask them how the act would have worked.
5. Reflection: Each group of students will explain their design strategy and how they used the properties of magnets in their act. Instructor should ask leading questions to get at the science behind the designs.

**Directed Instruction** *(10 minutes)*

1. Conservation of Energy: Energy can be neither created nor destroyed. Energy can by transferred from one object to another. Energy can also change forms.
   - Demonstration: Demonstrate Newton's Cradle and the transfer of energy. Explain that when the balls are held in the air, they have Potential Energy, a stored energy of position. When the balls are released they have Kinetic Energy, or an energy of motion. When the balls collide the energy is transferred pushing the balls on the other side away from the stack.
   - Questions:
     - 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?
2. Mechanical Advantage: Simple machines make work easier by providing a mechanical advantage (the ratio of effort to resistance). Simple machines reduce the amount of effort your need to move something, but the tradeoff is that you move it a greater distance to accomplish the same amount of work.
   - Real World Application Discussion: This discussion can take the form of being hypothetical or it can be a mini-challenge to identify useful tools and the simple machine they are an example of.
     - A student needs to open a closed can of paint. What tool would they use? *Lever/Wedge*

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  - A student needs to move a heavy load of books across the room and up to the second floor. What tool would they use? *A wheel and axel, an inclined plane, a pulley.*
- 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 the fulcrum to test the mechanical advantage 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:
    - 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?

**Motion Commotion: Part Two** *(30 minutes)*

1. Introduce the Challenge: Design and construct a "Rube Goldberg" style machine (with multiple steps) to ring a bell.
2. Introduce the 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.
3. Build: Give students about 20 minutes to build. Instructor should ask open-ended questions to help guide students through the design process, but should also allow students space to tinker.
4. Demonstration: Have students demonstrate their device for the class. If students have not completed their device ask them how the act would have worked.
5. Reflection: Each group of students will explain their design strategy and how they used the properties of magnets in their act. Instructor should ask leading questions to get at the science behind the designs.
   - 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?