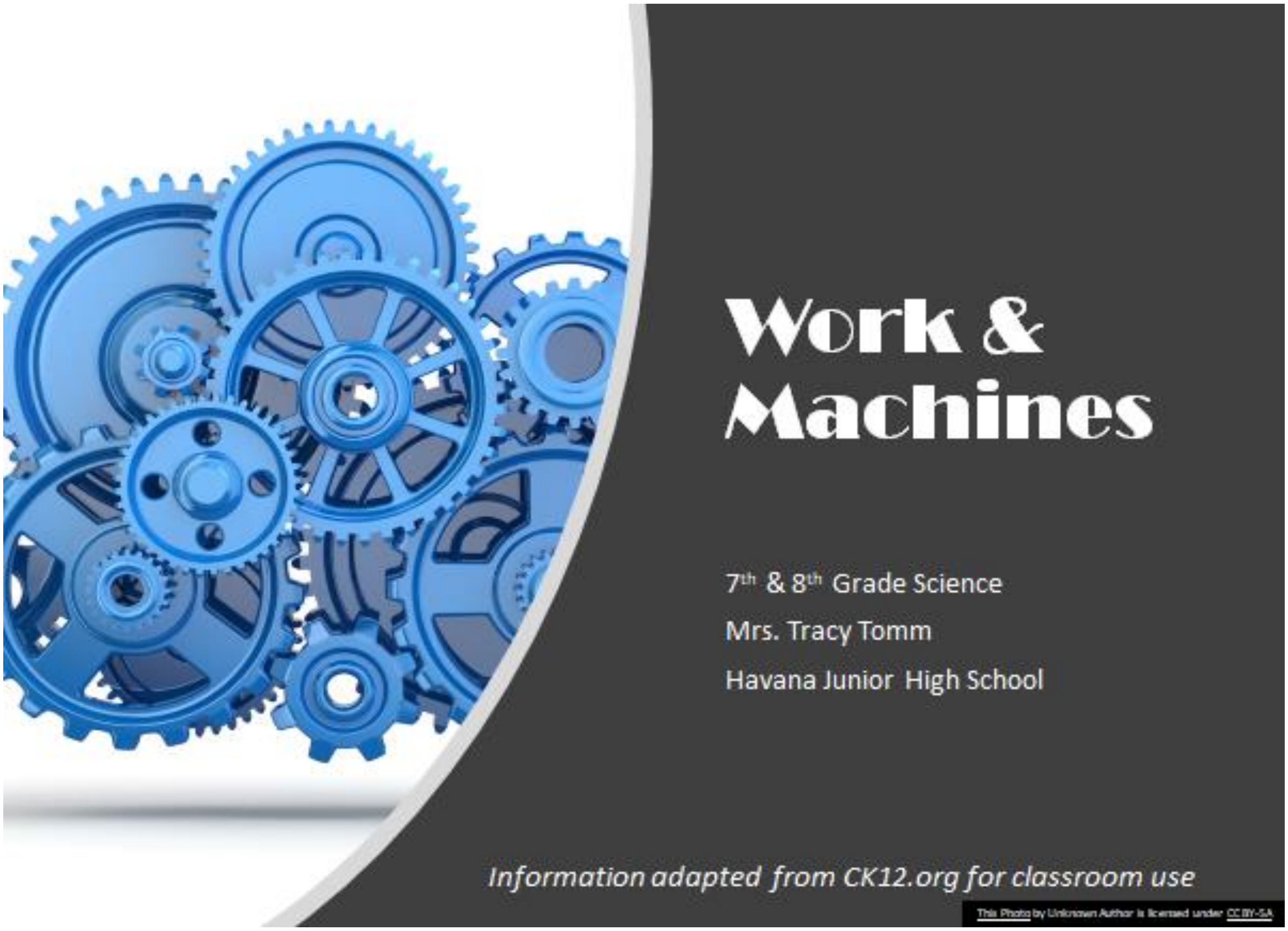

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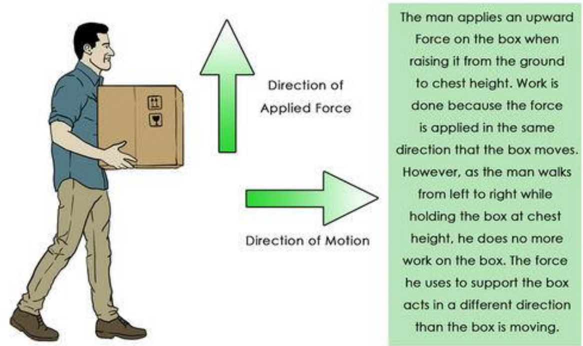
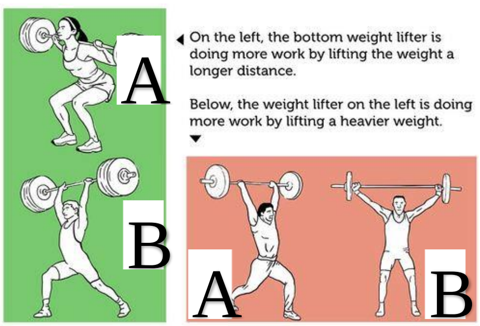
LESSON 1: WORK & POWER

What is work?

Work is defined differently in physics than in everyday language. In physics, **work** means the use of **force** (a push or a pull) to move an object.

Not all force that is used to move an object does work. For work to be done, the force must be applied in the same direction that the object moves. If a force is applied in a different direction than the object moves, no work is done. The figure illustrates this point.





Work is directly related* to both the force applied to an object and the distance the object moves. It can be represented by the equation: **Work = Force × Distance**.

The greater the force that is used to move an object or the farther the object is moved, the more work that is done.

Based on this information, which weightlifters are doing more work in each example in the picture at right?

What is power?

Did you ever sweep a floor with a broom? It can take a lot of effort to do the job. But if you use an electric vacuum cleaner, you can do the same work more easily and quickly. That's because the vacuum cleaner provides more **power**. **Power** is a measure of the amount of work that can be done in a given amount of time. Power can be represented by the equation: **Power=Work x Time**.

What are the units?

Force is expressed in **Newtons (N)** and distance is expressed in **meters** (**m**), which makes the unit for work the **Newton • meter** (**N • m**) (force x distance). This is also called the **joule (J)**, since one joule equals the amount of work that is done when 1 N of force moves an object over a distance of 1 m.

Since work is measured in **joules (J)** and time is measured in **seconds (s)**, power is expressed in joules per second (J/s). This is also known as the **watt (W)**. A watt equals 1 joule of work per second.

Sometimes power is measured in a unit called the **horsepower**. One horsepower is the amount of work a horse can do in 1 minute. It equals 746 watts of power. Compare the horsepowers in the figures below.

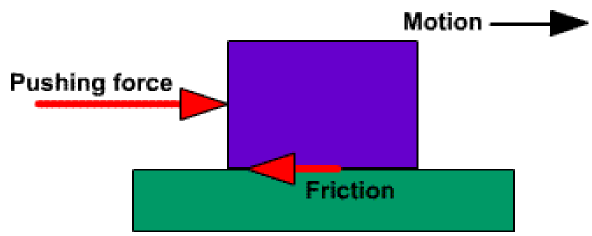
The team of three horses provides 3 horsepowers of power vs. a big tractor provides 180 horsepowers of power.

* *Direct relationship = As one variable increases so does the other or as one decreases so does the other.*

Lesson 2: Friction and Efficiency

What is friction?

Friction is the force that opposes motion between any surfaces that are touching. While all machines make work easier, they don't increase the amount of work that is done. You can never get more work out of a machine than you put into it. In fact, a machine always does less work on an object than the user does on the machine. That's because a machine must use some of the work put into it to overcome **friction**. All machines involve motion, so they all have friction.

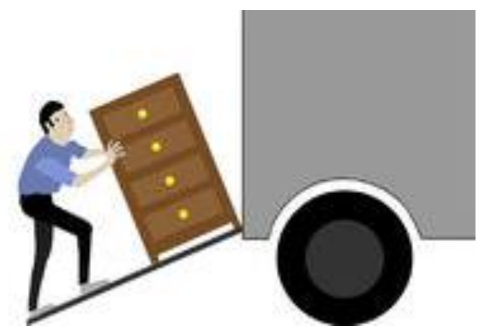


The three types of friction are **sliding**, **rolling**, and **fluid** friction. **Sliding** friction occurs between an object moving over a surface, such as pushing a box across a floor. **Rolling** friction occurs between a rotating object and the surface, such as wheels on a car. **Fluid** friction occurs between an object and a fluid, such as air, water, or oil. Air resistance is a type of fluid friction. Go to https://youtu.be/H877C_5BMkIto to learn more.

What is efficiency?

Efficiency is the percent of work put into a machine by the user (input work) that becomes work done by the machine (output work). The output work is always less than the input work because some of the input work is used to overcome **friction**. Therefore, efficiency is always less than 100 percent. The closer to 100 percent a machine's efficiency is, the better it is at reducing friction.

Look at the ramp in the figure. It is easier to push the heavy piece of furniture up the ramp to the truck than to lift it straight up off the ground but pushing the furniture over the surface of the ramp creates a lot of friction. Some of the force applied to moving the furniture must be used to overcome the friction with the ramp.



How do you determine efficiency?

Efficiency can be calculated with the equation:
Efficiency = Output work/Input work×100%

Consider a machine that puts out 6000 joules of work. To produce that much work from the machine requires the user to put in 8000 joules of work. To find the efficiency of the machine, substitute these values into the equation for efficiency: 6000 J/8000 J×100%=75%

Think About It: What can be done to improve a machine's efficiency?

Lesson 3: Simple & Compound Machines

What is a machine?

A **machine** is any device that makes work easier by changing a force. When you use a machine, you apply force to the machine (**input force)** and the machine applies force to an object (**output force**.) The output force may or may not be the same as the input force. Machines make work easier by increasing the amount of force that is applied, increasing the distance over which the force is applied, or changing the direction in which the force is applied.

Machines can be used to:

- **Increase force**, such as steering wheels and pliers. The machine applies more force than the user applies to the machine, but the machine applies the force over a shorter distance.
- **Increase the distance over which force is applied**, such as leaf rakes and hammers. The machine increases the distance over which the force is applied, but it reduces the strength of the force.
- **Change the direction of the force applied by the user**, such as the claw ends of hammers and flagpole pulleys. The direction of the force applied by the user is reversed by the machine

When you turn a steering wheel, it causes the smaller steering column in the center of the wheel to turn. The steering column turns a shorter distance but with greater force. The force applied by the steering column is great enough to turn the wheels of the car.

When you press together the two handles of the pliers, it causes the other ends of the handles to squeeze an object, such as the cord in this photo. The squeezing ends move a shorter distance but with greater force, so the pliers squeeze the object harder than you could with your fingers alone.

When the woman applies force to the handle end of the rake, she moves it over a short distance. The other end of the rake moves over a greater distance but with less force. By covering a greater distance, the rake can do more work than the woman could do with her hands alone.

When a carpenter moves the handle of the hammer back and forth a short distance with strong force, the head of the hammer moves a greater distance back and forth against the nail but with less force. By repeatedly hitting the nail, the hammer drives the nail into the board.

When the user of the hammer pushes down on the handle, the claw of the hammer pulls up on the nail. The hammer changes the direction of the force. It also applies greater force over a smaller distance.

The rope on a flagpole wraps around the pulley, which is a wheel with a groove in the rim. When a person pulls down on one end of the rope, the other end of the rope pulls up on the flag. However, the pulley doesn't change the strength of the force or the distance over which it is applied.

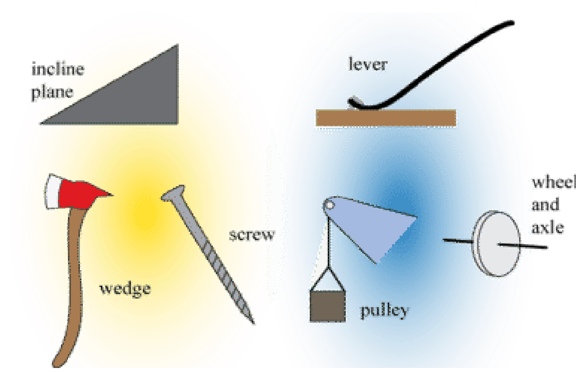
Simple vs. Compound Machines

There are six types of **simple machines** that are the basis of all other machines as pictured at right. Machines are made up of two or more simple machines are called **compound** machines. An example of a compound machine is a wheelbarrow. It consists of two simple machines: a lever and a wheel and axle.

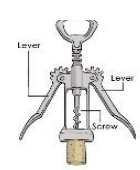
The **mechanical advantage** is the factor by which a machine changes the input force. The mechanical advantage is the increase or decrease in force that would occur if there were no friction to overcome in the use of the machine. In other words, it tells us how the input or effort force is increased or decreased when we use the machine.

Each simple machine is described on the following pages along with how to determine the mechanical advantage for each.

Simple Machines

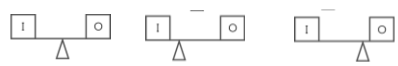
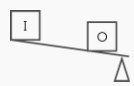
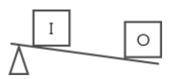


Compound Machines



Lever

A **lever** is a simple machine consisting of a bar that rotates around a fixed point. The fixed point of a lever is called the **fulcrum**. Like other machines, a lever makes work easier by changing the force applied to the machine or the distance over which the force is applied. The **input force** is the force applied by the user to the lever. The **output force** is the force applied by the lever to the object. There are three basic types of levers, called **first-class**, **second-class**, and **third-class** levers as shown in the table below. The classes are based on where the **input** and **output forces** are relative to the **fulcrum**.

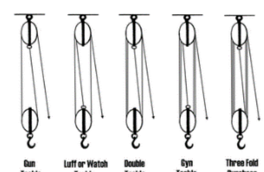
Class	Example	Input & Output Forces & Fulcrum*	Ideal Mechanical Advantage
First class			1 < 1 > 1
Second class			> 1
Third class			< 1

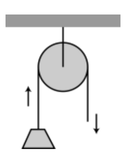
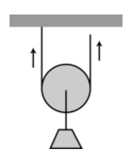
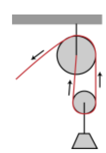
- Δ = fulcrum I = input force O = output force

Pulley

A **pulley** is a simple machine that consists of a rope and grooved wheel. The rope fits into the groove in the wheel and pulling on the rope turns the wheel. The object lifted by a pulley is called the **load**. The force applied to the pulley is called the **effort**.

Some pulleys, called **fixed pulleys,** are attached to a beam or other secure surface and remain fixed in place. Other pulleys are attached to the object being moved and are **moveable pulleys**. Fixed and moveable pulleys are used together to form a **compound pulley**, such as in the **block and tackle systems** shown in the image. The three types of pulleys are compared in the table.



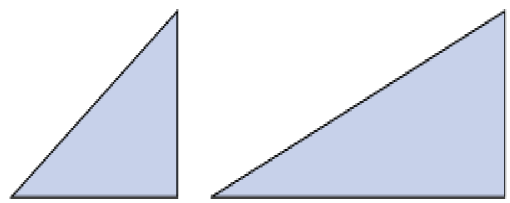
Type	Single fixed pulley	Single moveable pulley	Compound pulley (fixed & moveable pulleys)
How It Works			
Mechanical Advantage	1	2	≥ 2

In a pulley, the ideal mechanical advantage is equal to the **number of rope segments pulling up** on the object. The more rope segments that are helping to do the lifting work, the less force that is needed for the job, but the rope must be pulled a greater distance.

Inclined Plane

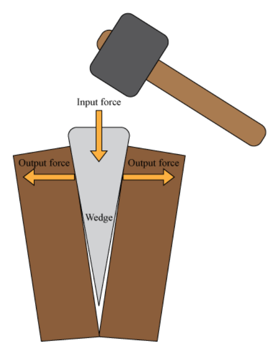
An **inclined plane** is a simple machine that consists of a sloping surface connecting a lower elevation to a higher elevation. An inclined plane is one of six types of simple machines, and it is one of the oldest and most basic. In fact, two other simple machines, the wedge and the screw, are variations of the inclined plane.

A ramp like the one in the figure is another example of an inclined plane. Inclined planes make it easier to move objects to a higher elevation. The sloping surface of the inclined plane supports part of the weight of the object as it moves up the slope. As a result, it takes less force to move the object uphill. The trade-off is that the object must be moved over a greater distance than if it were moved straight up to the higher elevation.

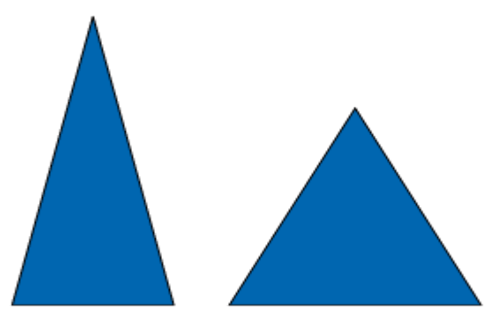


For an inclined plane, less force is put into moving an object up the slope than if the object were lifted straight up, so the mechanical advantage is greater than 1. The more gradual the slope of the inclined plane, the less input force is needed and the greater the mechanical advantage. Getting a piano into a truck isn't easy, so we often use a ramp to lower the amount of required force. Although the force is smaller, the distance we have to apply the force is greater, we exchange force for distance. However, the total amount of work done remains the same.

Wedge



A **wedge** is simple machine that consists of two inclined planes, giving it a thin end and thick end, as you can see in the figure. A wedge is used to cut or split apart objects. Force is applied to the thick end of the wedge, and the wedge, in turn, applies force to the object along both of its sloping sides. This force causes the object to split apart. A knife is another example of a wedge The job is easy to do with the knife because of the wedge shape of the blade. The very thin edge of the blade easily enters and cuts through the pecans.

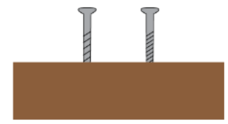


The mechanical advantage of a wedge is greater than 1. A longer, thinner wedge has a greater mechanical advantage than a shorter, wider wedge.

Which wedge in the figure do you think would do the same amount of work with less input force? The wedge on the left has a greater mechanical advantage, so it would do the same amount of work with less input force.

Screw

A **screw** is an inclined plane wrapped around a central cylinder. No doubt you are familiar with screws like the wood screw in the left-hand side of the figure. The cap of the bottle pictured on the right is another example of a screw. Screws move objects to a greater depth by increasing the force applied to the screw. When you use a screw, you apply force to turn the inclined plane. The screw, in turn, applies greater force to the object, such as the wood or bottle top.



The mechanical advantage of a screw is always greater than 1. Look at the two screws in the figure. In the screw on the right, the threads of the inclined plane are closer together, so it has a greater mechanical advantage. It is easier to turn than the screw on the left and it takes less force to penetrate the wood with the right screw. The trade-off is that more turns of the screw are needed to do the job because the distance over which the input force must be applied is greater.

Why is it harder to turn a screw with more widely spaced threads? The screw moves farther with each turn when the threads are more widely space, so more force must be applied to turn the screw and cover the greater distance.

Wheel & Axle

A **wheel and axle** consists of two connected rings or cylinders, one inside the other. Both rings or cylinders turn in the same direction around a single center point. The inner ring or cylinder is called the axle, and the outer one is called the wheel. Besides the Ferris wheel, gears and doorknobs are other examples of.

In a wheel and axle, force may be applied either to the wheel or to the axle. This force is called the input force. A wheel and axle does not change the direction of the input force. However, the force put out by the machine, called the output force, is either greater than the input force or else applied over a greater distance.

A wheel and axle may either increase or decrease the input force, depending on whether the input force is applied to the axle or the wheel. When the input force is applied to the axle, as it is with a Ferris wheel, the wheel turns with less force. Because the output force is less than the input force, the mechanical advantage is less than 1. However, the wheel turns over a greater distance, so it turns faster than the axle. The speed of the wheel is one reason that the Ferris wheel ride is so exciting. When the input force is applied to the wheel, as it is with a doorknob, the axle turns over a shorter distance but with greater force, so the mechanical advantage is greater than 1. This allows you to turn the doorknob with relatively little effort, while the axle of the doorknob applies enough force to slide the bar into or out of the doorframe.

Lesson 3 Review – Read Lesson 3 to help you answer these questions.

1. Find two examples of each type of simple machine in your home, yard, or garage.

Levers	
Pulleys	
Inclined Planes	
Wedges	
Screws	
Wheel & Axle	

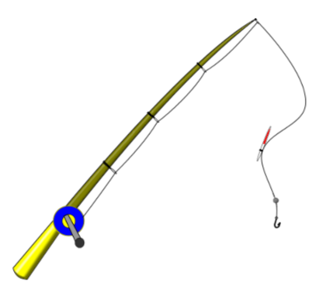
2. Identify ways to make a simple machine easier to use, i.e. require less force, by increasing its mechanical advantage.   Explain with words and provide drawings for each.

Lever

Pulleys

Inclined planes

3. Identify as many simple machines as you can in the two examples of compound machines below.



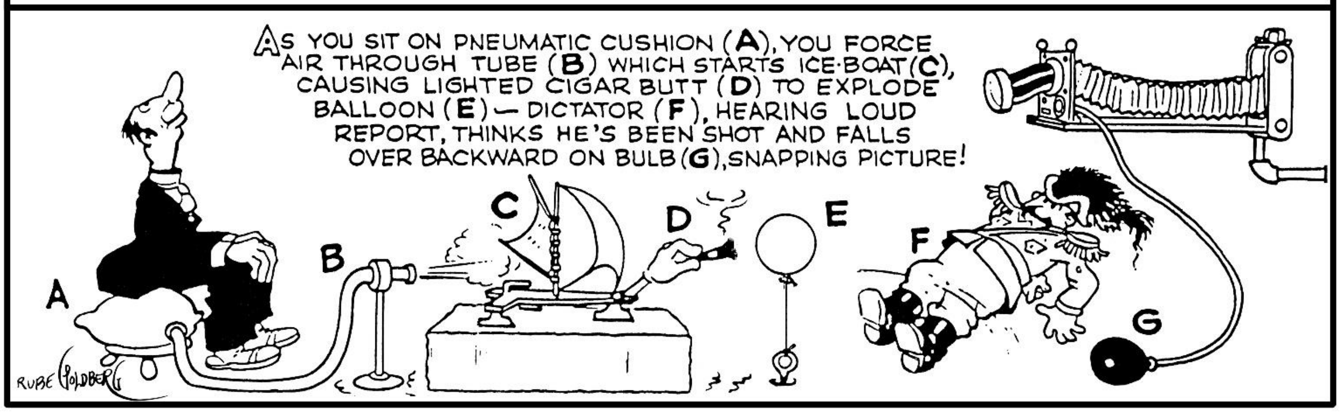
Lesson 4: Rube Goldberg

Source: https://www.rubegoldberg.com/the-man-behind-the-machine/

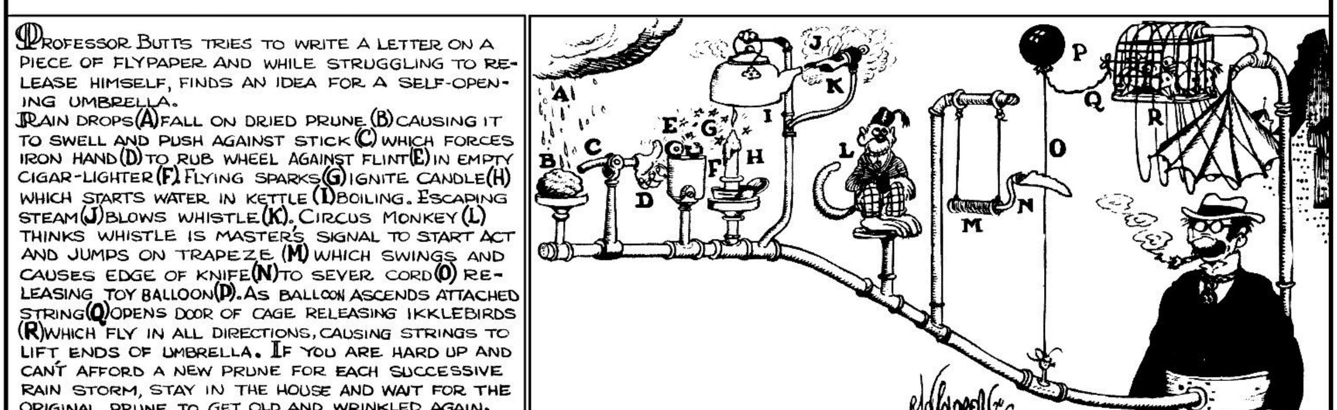
Rube Goldberg (1883-1970) was a Pulitzer Prize winning cartoonist best known for his zany invention cartoons. He was born in San Francisco on the 4th of July, 1883 – and graduated from U. Cal Berkeley with a degree in engineering. His first job at the San Francisco Chronicle led to early success, but it wasn't until he moved to NYC and began working for Hearst publications that he became a household name.

Rube Goldberg is the only person ever to be listed in the Merriam Webster Dictionary as an adjective. It's estimated that he did a staggering 50,000 cartoons in his lifetime. Rube is best known for the zany contraptions of Professor Butts. These inventions, also known as Rube Goldberg Machines, solved a simple task in the most overcomplicated, inefficient, and hilarious way possible. Examples of his work are shown below.

Picture Snapping Machine by Rube Goldberg



Self Opening Umbrella



Think About It - How many different types simple machines can you identify in each of these contraptions?

Work & Machines Unit Vocabulary

Compound Machine: A machine made of more than one simple machine
Compound Pulley: Two or more pulleys working together
Efficiency: The percentage of the input work that is converted to output work
Energy: The ability to do work or cause change
Fixed Pulley: A pulley that is attached to a structure
Fluid: Friction due to a fluid, such as air resistance
Force: A push or pull
Friction: A force that occurs when one object rubs against another object
Fulcrum: The fixed point around which a lever pivots
Gravity: A force that pulls objects toward each other
Horsepower: A common unit of power, equal to about 746 watts
Inclined plane: A simple machine made up of a slanted surface
Input: Force applied to a simple machine
Joule: A unit of work equal to one newton-meter
Kinetic energy: The energy an object has due to its motion
Lever: A simple machine made up of a stiff bar that moves freely around a fixed point
Mechanical Advantage (MA): Factor by which a machine multiplies the effort force
Motion: A change in the position of an object as compared to objects around it
Moveable pulley: A pulley that moves with the load or resistance
Newton: SI unit of force
Output: Force created or applied by a simple machine
Potential energy: Stored energy that results from the position or shape of an object
Power: The rate at which work is done; measured in watts
Pulley: A simple machine made up of a rope fitted around the rim of a fixed wheel
Rolling: Friction between a rolling object and the surface it rolls on
Rube Goldberg: The cartoonist who drew pictures of complex machines that do simple tasks.
Screw: A simple machine made up of an inclined place wrapped around a column
Simple Machine: One of the six basic types of machines, which are combined to make complex machines
Sliding: Friction that occurs when one solid surface slides over another
Watt: Unit for power
Wedge: A simple machine made up of two inclined planes placed back to back
Wheel and axle: A simple machine made up of two cylinders that turn on the same axis
Work: A result of a force moving an object a certain distance; force x distance

Additional Resources