Per 8 Activity Sheet: Work, Efficiency and Complex Machines

8.1 How Much Work is Done by Machines? How Efficient Are They?

a) Block and Tackle  Your instructor will use the block and tackle to lift blocks.

1) Find the work done when you pull the block and tackle rope. This is the work in.
   \[ \text{Work in} = F_{\text{in}} \times D_{\text{in}} \]

2) Find the work done on the blocks as they are lifted. This is the work out.
   \[ \text{Work out} = F_{\text{out}} \times D_{\text{out}} \]

3) Calculate the efficiency of the block and tackle.
   \[ \text{Efficiency} = \frac{\text{Work out}}{\text{Work in}} \]

b) Winch  Try a “tug of war” game with the winch in the front of the classroom.

1) Suppose you move the handle of the winch in a circle a distance of 112 meters (distance in). When you do, the winch rope moves 2 meters (distance out). If you exert a force of 280 newtons on the winch handle (force in), calculate how much work you do to move the winch handle a distance of 112 m.
   \[ \text{Work in} = F_{\text{in}} \times D_{\text{in}} = 280 \text{ N} \times 112 \text{ m} = 31,360 \text{ joules} \]
   \[ = 3.14 \times 10^4 \text{ J} \]

2) If the force out on the rope is 8,400 newtons, how much work out does the winch do as it pulls the rope a distance of 2 m?
   \[ \text{Work out} = F_{\text{out}} \times D_{\text{out}} = 8,400 \text{ N} \times 2 \text{ m} = 16,800 \text{ joules} \]
   \[ = 1.68 \times 10^4 \text{ J} \]

3) Calculate the efficiency of the winch.
   \[ \text{Efficiency} = \frac{\text{Work out}}{\text{Work in}} = \frac{1.68 \times 10^4 \text{ joules}}{3.14 \times 10^4 \text{ joules}} = 0.54 = 54\% \]

   \[ = 54\% \]

c) Wheels and Axles  The plastic bottle illustrates a wheel and axle trading force for distance. The middle of the bottle represents the wheel and the neck of the bottle represents the axle.

1) Measure the circumference of the neck of the bottle. This length represents the distance out. 

2) Measure the circumference of the middle of the bottle. This length represents the distance in.
In part 5 you will hang masses from the strings attached to the bottle. But first, make a prediction of the amount of mass needed.

3) Calculate how much force a 500 gram mass attached to the string around the neck of the bottle would exert on the string. This is the force out.  
\[ F = M \cdot g \]

4) Calculate how much force in hanging from the middle of the bottle is needed to balance the force out. (Hint: Use \( F_{\text{in}} \times D_{\text{in}} = F_{\text{out}} \times D_{\text{out}} \))

5) Convert the force in you calculated in part 4 into mass. This is your prediction of the amount of mass to hang from the middle of the bottle.
\[ M = \frac{F}{g} \]

Note: This gives the mass in kilograms. The values on the brass masses are in grams.

6) According to your calculation of the force out (part 3), how much work comes out of the system?
\[ \text{Work}_{\text{out}} = F_{\text{out}} \times D_{\text{out}} \]

7) How much work in goes into this system?
\[ \text{Work}_{\text{in}} = F_{\text{in}} \times D_{\text{in}} \]

8) Check your prediction. Hang a 500 gram mass from the string around the bottle neck. Hang the amount of mass you calculated in part 5 from the string around the middle of the bottle. If the work in equals the work out, the bottle should balance without rotating. Describe what happens when you attach the masses.

d) Group Discussion Question: If the bottle does not balance exactly, there may be another reason other than an error in your calculation of the mass. What could cause the work in to be not exactly equal to the work out in this system? Do you think the efficiency of this system is more than 1, equal to 1, or less than 1?

Friction in the system wastes some energy. Therefore, the work out is less than the work in, and the bottle may rotate. As with any machine, the efficiency is less than 1.

8.2 How Do Hydraulic Systems and Gears Work?
a) Hydraulic Machines The two connected syringes represent a hydraulic machine

1) Press the plunger of the small syringe in. Measure the distance in the small plunger moves _______ and the distance out the large plunger moves. _______

2) Calculate the theoretical mechanical advantage of the syringe set.
\[ MA_{\text{theoretical}} = \frac{D_{\text{in}}}{D_{\text{out}}} \]
3) Suppose that a force in of 9 newtons is required to exert a force out on the large plunger of 12 newtons. Calculate the efficiency of the syringe system.

\[
\text{Efficiency} = \frac{\text{Work}_{\text{out}}}{\text{Work}_{\text{in}}} = \frac{F_{\text{out}} \times D_{\text{out}}}{F_{\text{in}} \times D_{\text{in}}}
\]

4) List several devices that operate on the same principle as the syringes.

- Car brakes, car repair lifts, some elevators

b) **Gears**

1) Examine the gear toy. To make the edge of the outer gears turn the fastest, should the center gear be a small, medium, or large gear? Make a prediction and then experiment to check your guess.

**Prediction:** ___________________  **Answer:** __ Large gear __

2) Find a combination of 3 or more gears that make the yellow “flipping eyes” gear flip at the fastest rate. (Use 2 or more gears plus the flipping eyes gear. Put the flipping eyes farthest from the center.)

*The eyes flip fastest with the large gear in the center. Connect the eyes gear to the large center gear using any other gears.*

3) Find a combination or 3 or more gears that make the flipping eyes gear flip at the slowest rate.

*The eyes flip slowest with the small gear in the center. Connect the eyes gear to the small center gear using any other gears.*

4) Draw a sketch of your gear setups showing which gears you used.

**Eyes Flip Fastest**  **Eyes Flip Slowest**

### 8.3 What Are Complex Machines?

a) Your instructor will demonstrate the robotic arm. List some of the simple machines that make up the robotic arm.

*The robotic arm contains levers in the “arm” and “hand.” Gears inside the arm change the direction of motion.*

b) Examine the toy on your table made from a Capsela set and list its component simple machines. Starting at the battery, trace the toy’s moving components and explain how the toy works.

*All of the toys contain gears and levers. Some contain a pulley or winch. In the battery, stored chemical potential energy is converted into electrical energy, which operates a small electric motor. The motor turns a shaft. The rotating shaft turns gears that transfer kinetic energy to the toy’s wheels and turn them.*
c) Connect the electric winch to a hand-cranked generator. Hang a mass on the end of the winch string and raise the mass by cranking the generator handle.

1) How much mass did you hang on the winch?  __________
2) How much force does this mass exert on the winch?  \[ F = M g \]  __________
3) How far did you raise the mass?  __________
4) How much work did you do to raise the mass?  (Ignore any frictional forces.)
\[ W = M g h \]  __________
5) What are some of the simple machine components of the complex machine consisting of the hand-cranked generator and the winch?

The hand-cranked generator contains a lever and gears. The winch consists of a wheel and axle, gears, and a pulley.

8.4 What Is the Efficiency and Mechanical Advantage of a Complex Machine?

a) If a hydraulic machine with a mechanical advantage of 5 and an efficiency of 60% is connected to a block and tackle with a mechanical advantage of 4 and an efficiency of 50%, what is their overall mechanical advantage?
\[ M A_{\text{complex}} = M A_1 \times M A_2 = 5 \times 4 = 20 \]

b) What is the overall efficiency of the hydraulic machine connected to the block and tackle?
\[ \text{Eff}_{\text{complex}} = \text{Eff}_1 \times \text{Eff}_2 = 0.60 \times 0.50 = 0.30 = 30\% \]

c) Is it possible to combine simple machines to form a complex machine with a greater overall mechanical advantage than its component machines?  \_\_\_Yes\_\_

d) Is it possible to combine simple machines to form a complex machine with a greater overall efficiency than its component machines?  \_\_\_No\_\_

Explain why or why not.

Each of the component simple machines wastes some energy due to frictional forces. Thus, the efficiency of each component machine is less than one. When you multiply together numbers less than one, their product is smaller than the individual numbers.