Per 8 Activity Solutions: 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) How much weight did the block and tackle lift? ______________
2) How high off the floor were the cement blocks raised? ______________
3) Find the work done on the blocks to raise them. This is the **work out**.

   $\boldsymbol{Work_{out} = F_{out} \times D_{out}}$ __________

4) How much force was needed to raise the blocks? ______________
5) Through what distance was the rope pulled to lift them? ______________
6) Find the work done when you pull the block and tackle rope. This is the **work in**.

   $\boldsymbol{Work_{in} = F_{in} \times D_{in}}$ ____________

7) Calculate the efficiency of the block and tackle.

$$Efficiency = \frac{Work_{out}}{Work_{in}}$$

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 in must you do to move the winch handle a distance of 112 m.

   $\boldsymbol{Work_{in} = F_{in} \times D_{in} =}$ **280 N x 112 m = 31,360 joules**

   __3.14 x 10^4 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?

   $\boldsymbol{Work_{out} = F_{out} \times D_{out} =}$ **8,400 N x 2 m = 16,800 joules**

   __1.68 x 10^4 J___

3) Calculate the efficiency of the winch.

   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%

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. We will hang a weight from the wheel (the center of the bottle) to do work on a weight attached to the axle (the neck of the bottle).

1) Measure the circumference of the middle of the bottle. _________
   Take ½ of this length to find the **distance in.** _______________
   (We use ½ of the length because the bottle can move only ½ turn.)

2) Measure the circumference of the neck of the bottle. _________
   Take ½ of this length to find the **distance out.** _______________

3) Attach a 5 newton weight to the string around the neck of the bottle (the axle). This is the **force out.**

4) Calculate how much force must hang from the string around the middle of the bottle (the wheel) to balance the 5 N force hanging from the bottle neck. This is the **force in.**

   (Hint: Assume that the bottle is frictionless, so that W_{out} done on the weight to raise it equals W_{in}. Then use $F_{in} \times D_{in} = F_{out} \times D_{out}$)

$$F_{in} = \frac{F_{out} \times D_{out}}{D_{in}}$$

5) Check your prediction. With the 5 N weight hanging from the bottle neck, hang weights totaling the force you found in part 4 from 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 weights.

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 force in. 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. Using a ruler, 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.

   use $MA_{theoretical} = D_{in} / D_{out}$

3) Suppose that a force in of 3 newtons is required to exert a force out on the large plunger of 12 newtons. Calculate the actual mechanical advantage of the syringe system.

use $MA_{actual} = F_{out} / F_{in}$

4) Calculate the efficiency of the syringe system.

$$\text{Efficiency} = \frac{Work_{out}}{Work_{in}} = \frac{F_{out} \times D_{out}}{F_{in} \times D_{in}} \quad \text{or} \quad \text{Efficiency} = \frac{MA_{actual}}{MA_{theoretical}}$$

5) 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 smaller or larger than the outer gear? Make a prediction and then experiment to check your guess.

Prediction: ______________________ **Answer:** ______________________

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 the Efficiency and Mechanical Advantage of Complex Machines?

a) Examine the toy on your table made from a Capsela set and list the simple machines you see.

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.

b) 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 the overall mechanical advantage of the complex machine?

$MA_{complex} = MA_1 \times MA_2 = 5 \times 4 = 20$

_____**20**____

c) What is the overall efficiency of the hydraulic machine and the block and tackle combined?

$Eff_{complex} = Eff_1 \times Eff_2 = 0.60 \times 0.50 = 0.30 = 30\%$

___**30%**___

d) Is it possible to combine simple machines to form a complex machine with a greater overall mechanical advantage than its component machines? _**Yes**_

e) 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.