Preview of Period 8: Work, Efficiency and Complex Machines

8.1 Work and Simple Machines
How much work can machines do?

8.2 Efficiency of Simple Machines
How efficient are machines?

8.3 More Simple Machines
How do hydraulic systems, winches, and gears work?

8.4 Complex Machines
How are simple machines combined into complex machines?
How are the efficiency and mechanical advantage of complex machines defined?
Review of Mechanical Advantage

Theoretical Mechanical Advantage

\[ \text{MA}_{\text{theoretical}} = \frac{D_{\text{in}}}{D_{\text{out}}} \]

- \( D_{\text{in}} \) = distance you move the machine
- \( D_{\text{out}} \) = distance the load moves

Theoretical mechanical advantage is an ideal case with no energy wasted by frictional forces.

Actual Mechanical Advantage

\[ \text{MA}_{\text{actual}} = \frac{F_{\text{out}}}{F_{\text{in}}} \]

- \( F_{\text{in}} \) = the force you exert on the machine
- \( F_{\text{out}} \) = the force exerted on the load by the machine

Actual mechanical advantage takes into account the energy wasted by frictional forces.
Act. 8.1: Work Done by Machines

\[ \text{Work} = \text{Force} \times \text{Distance} \]

\[ W = F \cdot D \]

For an object lifted by a machine,

\[ \text{Work} = \text{downward force of the load on the machine} \times \text{distance the load is raised} \]

If the downward force on the load equals the weight of the load,

\[ \text{Work} = \text{weight of load} \times \text{change in height} \]

\[ W = M \cdot g \cdot h \]

\[ W = \text{work done on the load (joules)} \]
\[ M = \text{mass of the object (kilograms)} \]
\[ g = \text{the acceleration of gravity} = 9.8 \text{ m/s}^2 \]
\[ h = \text{change in height of the load (meters)} \]
Act. 8.1: Efficiency of Machines

Efficiency \[=\] \( \frac{\text{Work you get out}}{\text{Work you put in}} \)

\[ \text{Eff} = \frac{\text{Work}_{\text{out}}}{\text{Work}_{\text{in}}} \]

\( W_{\text{in}} = \) work put into the machine (joules or foot-pounds)

\( W_{\text{out}} = \) work done by the machine (joules or foot-pounds)

Machines do not reduce the amount of work needed.

Since some energy is wasted overcoming frictional forces, the amount of work required using a machine is greater than the amount of work required without a machine.

Why use machines if they require more work? Try the “tug of war” activity. Could you exert this much force without a machine?
Act. 8.1: Efficiency of Simple Machines

Sample Calculation

(Example 8.1)

A machine requires 2,000 joules of energy to raise a 20 kilogram block a distance of 6.0 meters. What is the machine’s efficiency?

First, find the work done to raise the block:

\[ W = M \cdot g \cdot h = 20 \text{ kg} \cdot 9.8 \text{ m/s}^2 \cdot 6.0 \text{ m} = 1,176 \text{ J} \]

Next, use the efficiency equation. The work in equals 2,000 joules.

\[
\text{Eff} = \frac{\text{Work}_{\text{out}}}{\text{Work}_{\text{in}}} = \frac{1,176 \text{ joules}}{2,000 \text{ joules}} = 0.59 = 59\%
\]
Act. 8.1.c: Wheels and Axles

- When wheels with different diameters are attached to an axle, they trade force for distance.

- With each turn of the axle both wheels rotate one turn.

- If the wheels have different diameters, the edge of each wheel turns a different distance and speed.

A force applied to the **large wheel** multiplies the force of the small wheel.

A force applied to the **small wheel** multiplies the speed that the edge of the large wheel turns.
Act. 8.2  Gears

• Force applied to a large gear, which is meshed with a small gear, results in greater speed.

• When driving on a level highway, force is applied to a large diameter, which turns a small diameter gear. This gear ratio is used to maximize speed.

• To start a car from rest, force is applied to a small diameter gear, which turns a larger diameter gear. This gear ratio is used to maximize the car’s acceleration.

The small gear turns faster.

The large gear turns slower.

If a small gear has _ the circumference of a large gear, the small gear turns 2 times for every one turn of the large gear.
Act. 8.3: Complex Machines

Complex machines are combinations of simple machines.

Find the simple machines that make up

♦ The robotic arm

♦ The clear plastic moving toy

♦ The electric winch connected to a hand-cranked generator
Act. 8.4: The Efficiency of Complex Machines

\[ \text{Eff}_{\text{complex}} = \text{Eff}_1 \times \text{Eff}_2 \times \text{Eff}_3 \ldots \]

\[ \text{Eff}_{\text{complex}} = \text{efficiency of the complex machine} \]
\[ \text{Eff}_1 = \text{efficiency of the first simple machine} \]
\[ \text{Eff}_2 = \text{efficiency of the second simple machine} \]
\[ \text{Eff}_3 = \text{efficiency of the third simple machine} \]

(Ex. 8.2)

A complex machine consists of a pulley system and a lever. The efficiency of the pulley is 40% and the efficiency of the lever is 60%. What is the efficiency of the complex machine?

\[ \text{Eff}_{\text{complex}} = \text{Eff}_{\text{pulley}} \times \text{Eff}_{\text{lever}} = \]

\[ 0.40 \times 0.60 = 0.24 = 24\% \]
Act. 8.4: The Mechanical Advantage of Complex Machines

\[ MA_{\text{complex}} = MA_1 \times MA_2 \times MA_3 \]

- \( MA_{\text{complex}} \) = mech. adv. of the complex machine
- \( MA_1 \) = mech. adv. of the first simple machine
- \( MA_2 \) = mech. adv. of the second simple machine
- \( MA_3 \) = mech. adv. of the third simple machine

(Ex. 8.3)

A complex machine has a pulley system with 3 rope segments supporting the load and a lever, which requires 50 lbs of force in to get 200 lbs of force out. What is the mechanical advantage of the complex machine?

\[
MA\text{ of 3 supporting rope segments} = 3
\]

\[
MA\text{ of lever} = \frac{\text{Force out}}{\text{Force in}} = \frac{200 \text{ lbs}}{50 \text{ lbs}} = 4
\]

\[
MA_{\text{complex}} = MA_{\text{pulley}} \times MA_{\text{lever}}
\]

\[
= 3 \times 4 = 12
\]
Period 8 Summary

8.1: Machines can reduce the force required to perform a task, but not the work required.

Ignoring the energy wasted by friction, the work put into a machine equals the work out.

When the energy wasted by frictional forces is taken into account, more work is required to perform a task with a machine than without one.

The work done to lift a load: \[ W = Mg h \]

8.2: Efficiency = Useful Work Out/ Work In

The efficiency of machines is always less than 100% since some energy is wasted.

8.3: Wheels and axles maximize the speed and distance of a large wheel when force is applied to a small wheel. Force out is maximized when force is applied to a large wheel.
Period 8 Summary, Continued

Gears: Gears are combinations of wheels with teeth. Force applied to a large gear, which is meshed with a small gear, results in greater speed out.

Winches trade force for distance. Force is applied to a large diameter crank to wind a rope attached to a small diameter axle.

Hydraulic pistons filled with fluid trade force for distance in elevators, automobile lifts, and construction machinery.

8.4: Complex machines are combinations of two or more simple machines.

\[ \text{Eff}_{\text{complex}} = \text{Eff}_1 \times \text{Eff}_2 \times \text{Eff}_3 \ldots \]

\[ \text{MA}_{\text{complex}} = \text{MA}_1 \times \text{MA}_2 \times \text{MA}_3 \ldots \]
Period 8 Review Questions

**R.1** How does a winch reduce the amount of force needed to raise an object? Can a winch reduce the amount of work required? Why or why not?

**R.2** Two gears turn together. If the larger gear has a diameter twice that of the smaller gear, how many times will the larger gear turn when the smaller gear turns 50 times?

**R.3** Explain how to calculate the efficiency of a simple machine. How would you calculate the efficiency of a complex machine?

**R.4** Can you combine simple machines to form a complex machine with a greater overall efficiency than its component machines? Why or why not?

**R.5** Is it possible to combine simple machines to form a complex machine with a greater overall mechanical advantage than its component machines? Why or why not?