UNIT D

Mechanical Systems

In this unit, you will cover the following sections:

1.0 **Machines are tools that help humans do work.**

1.1 Simple Machines—Meeting Human Needs

1.2 The Complex Machine—A Mechanical Team

2.0 **An understanding of mechanical advantage and work helps in determining the efficiency of machines.**

2.1 Machines Make Work Easier

2.2 The Science of Work

2.3 The Big Movers—Hydraulics

3.0 **Science, society, and the environment are all important in the development of mechanical devices and other technology.**

3.1 Evaluating Mechanical Devices

3.2 Technology Develops through Change

Exploring

The Da Vinci robotic arm allows surgeons to operate through small incisions. It also makes operating at a distance possible.

In July 2000, the first surgical robotic arm was approved for use in North America. Named "Da Vinci," this device helps surgeons perform operations inside people through very small incisions. This type of surgery is called "remote surgery" because the surgeon is not directly touching the patient. In fact, with this new system, the surgeon doesn't even have to be in the same room with the patient. The surgeon can do the operation from another location. The patient's local doctor needs only a connected computer, a video terminal, and the Da Vinci arm.

Mechanical Arm Provides More Control

The robotic arm is inserted through one small incision, and a tiny camera is inserted through a second incision. The surgeon then watches on a television screen to perform the operation. The Da Vinci robotic arm has a built-in "wrist" for flexibility. This feature and the size of the arm make it easier for surgeons to work on smaller tissues, such as nerves or blood vessels. With Da Vinci's help, surgeons can work in very small spaces and not worry about trembling from tired hands! The surgical robotic arm gives surgeons more control during surgery than ever before.

Benefits to patients include less recovery time for major operations. In the past, doctors had to make large incisions that would completely expose the organ they were operating on. The tiny incisions in a Da Vinci–assisted operation mean that the patient will heal more quickly.

The Da Vinci arm has a flexible mechanical "wrist" so that it can make the necessary movements for surgery.

A System of Components Working Together

Remotely controlled machines, such as the Da Vinci surgical system, rely on several smaller components and technologies in order to work. A computer controls the instruments as if the surgeon was controlling the very tip of the scalpel in person. The motions of the surgeon's hands are transferred to hydraulic pumps and electric motors that control the scalpel, drill, and scissors at the end of the robotic arm. The sensitivity of the tools is adjusted by combinations of miniature gears, levers, and pulleys.

The development of a complex machine such as a robotic arm is the result of teams of people working together. They use their knowledge of mechanical systems and apply the latest technology to solve problems.

Give it a **TRY** ACTIVITY

Emergency!

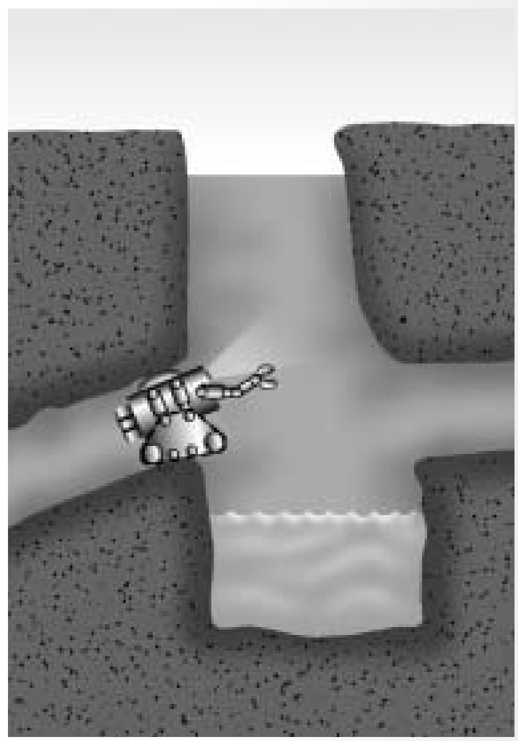
TOOLBOX

Now you have an opportunity to work as part of a team in solving a problem. You and your group are part of the Emergency Robotic Environmental Response unit at RoboQuest Inc. An accident has just occurred. A robotic probe exploring a mining drainage pit has become wedged in a small passage. The probe is very heavy—about 100 kg. Your task is to retrieve the probe without damaging it. You can see from the diagram of the accident site that this will be a challenge.

Design a device that can help you extract the probe. Include the equipment listed below in your design:

- a mechanical arm
- steel beams about 2 m long
- an assortment of gears
- an assortment of pulleys with ropes

Before you start, read through Toolbox 3 to learn about problem-solving techniques.



The accident site

Focus On SCIENCE AND TECHNOLOGY

As you work through this unit, you will learn how machines help us do a variety of tasks. You will work with different mechanical systems to identify their components. You will also determine their impact on you and on the environment. Through this work, you will be able to understand better how science and technology are related. Scientific knowledge leads to the development of new technologies. In turn, new technologies lead to scientific discoveries.

The activities in this unit focus on your developing solutions to practical problems. Often these problems have more than one possible solution. You will learn to evaluate the options to find the best solution. You will also develop your problem-solving skills as you analyze working models of different types of machines to determine their strengths and weaknesses. At the end of the unit, you will use your understanding of mechanical systems and your skills in a final project. In this project, you will build a working prototype of a mechanical gripper device.

As you work through this unit, use the following four questions to guide your learning about mechanical systems:

1. **How is energy transferred in mechanical devices?**
2. **How do mechanical devices provide for the controlled application of force?**
3. **How do mechanical devices work efficiently and effectively to meet human needs?**
4. **What are the social and environmental impacts of mechanical devices?**

1.0 Machines are tools that help humans do work.

Key Concepts
In this section, you will learn about the following key concepts:
- systems and subsystems
- transmission of force and motion
- simple machines

Learning Outcomes
When you have completed this section, you will be able to:
- describe examples of mechanical devices used in the past to meet particular needs
- describe an example of how a common need has been met in different ways over time
- analyze a mechanical device by describing how different parts contribute to its overall function and identifying the parts that are simple machines
- identify the sources of energy for some familiar mechanical devices
- identify linkages and transmissions in a mechanical device and describe their general functions

Since farming began over 7000 years ago, humans have been creating ever more sophisticated tools and machines. Machines help people use energy more effectively. In other words, a **machine** is a device that helps us do work.

The combine harvester shown here was developed to make harvesting crops easier and quicker for farmers. Early combines were pulled by horses or tractors. Later they were motorized, and today they are computerized and air-conditioned as well. Developments in technology for control systems, motors, materials, and other areas have all contributed to the design of these new combines.

In this section, you will learn about simple machines and how they help people perform tasks. You will learn that simple machines can work together in a system to form a complex machine. You will also discover how linkages and transmissions transfer energy in machines.

For Web links relating to 1.0, visit **www.pearsoned.ca/scienceinaction**

1.1 Simple Machines—Meeting Human Needs

The earliest machines were very simple devices. For example, people used levers to pry rocks out of the ground. Then they used a ramp to help them raise the rocks as they built walls and other large structures. Each machine was designed to meet specific needs, such as lifting rocks or splitting wood. Although each machine was different, they all had one thing in common. These first machines depended on people or animals for their source of energy.

Working with a partner, try to determine what tasks the historic machines in Figure 1.1 were used for and how they worked. Look for clues in the pictures, or research the names of the machines to find out what needs these machines were designed to meet. Also, try to determine the approximate time periods when these machines were used.

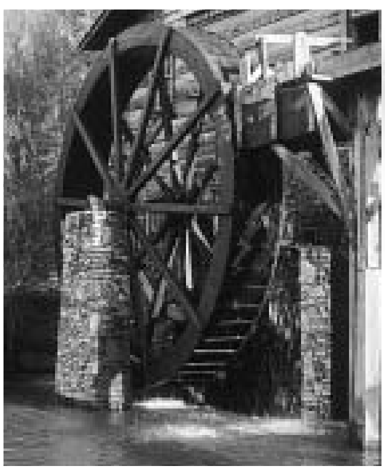


Figure 1.1a) Mill wheel

Figure 1.1b) Nutcracker

Figure 1.1c) Plow

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Roman Aqueducts

Thousands of years ago, Roman engineers developed a mechanical system for transporting water for many kilometres to supply major cities. These structures, known as aqueducts, were made up of three main parts:

1. pumps to raise the water into reservoirs and control the rate of water flow
2. sloped channels to carry the water to the cities
3. distribution systems in the cities to carry the water to central bathhouses and local reservoirs

The aqueducts were so well designed and constructed that many of them can still be seen today in Europe, more than 2000 years after they were built!

Meeting the Same Need in Different Ways

One of the most basic human needs is fresh water. You have running water in your home because of a combination of mechanical systems. These systems move water from its source, through a series of pipes, to your tap. Pumps powered by electricity keep the water moving.

Before pumps were available, people used gravity to move water. Water was stored in large, raised tanks. Gravity caused it to move down from the pipes through tanks to where it was needed in the community.

In the past, one of the most common ways of raising water into these tanks was a type of water wheel called a *sakia* (also called a Persian wheel). A sakia has a series of buckets attached to a long rope, which is draped over a large wheel. Animals such as donkeys, camels, or cows turned the wheel, which raised the buckets of water.

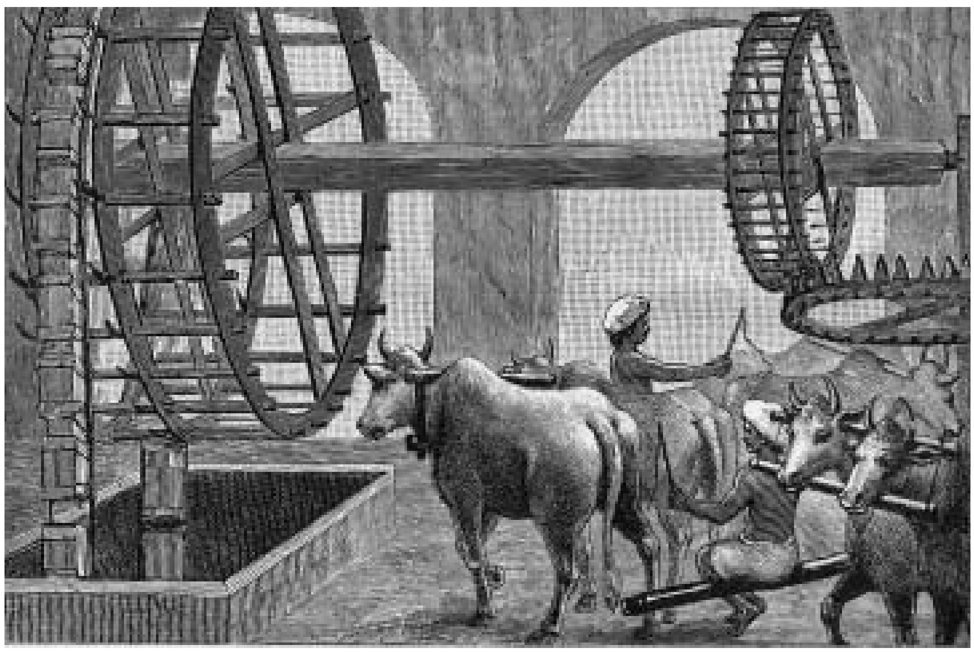


Figure 1.2 A sakia can be used to haul water out of a well for storage in large tanks or for irrigation.

Archimedes Invents a More Efficient Way

Although the sakia worked well in lifting water, people were always looking for more efficient ways to do this task. One of these methods was invented by the famous Greek scientist and mathematician Archimedes. His device used a large screw inside a tube. One end of the tube is placed in water. When the screw turns, it raises water up to the top of the tube. Called an Archimedes screw, this device can move large volumes of water or other substances. Originally it was powered by hand. Today it is powered by gasoline or electric motors.

Hundreds of years later, the famous Italian scientist Leonardo da Vinci designed a water lift using two Archimedes screws to raise water up to a storage tank in a water tower. His original plans are shown in Figure 1.3. The Archimedes screw is still in use today. Figure 1.4 shows a modern example of an Archimedes screw being used to move grain into a truck.

Figure 1.3 Leonardo da Vinci's design for using two Archimedes screws to raise water up into a water tower.

Figure 1.4 The spiral motion of the slowly turning screw moves the grain into the truck.

Simple Machines

The earliest machines, known as simple machines, are still used today. A **simple machine** is a tool or device made up of one basic machine. In their work, engineers must be aware of the strengths and limitations of each type of simple machine. This knowledge enables them to design combinations of these machines to do complicated tasks.

Before you read about the advantages and disadvantages of each simple machine, make a chart in your notebook similar to the one below. Fill in your chart as you read about the different machines.

Simple Machine	Advantages	Disadvantages
lever		

There are six simple machines that help us do work: the lever, inclined plane, wedge, screw, pulley, and wheel and axle. Each one is used for specific tasks. Each has its own advantages and disadvantages.

Lever

The **lever** is a rigid bar or plank that can rotate around a fixed point called a *pivot* or *fulcrum*. Levers are used to reduce the force needed to carry out a task such as pulling a nail, opening a bottle, hitting a baseball, and cutting paper. With a lever you can move a larger load than you could without using it. However, to do that, you must move a greater distance than the load does.

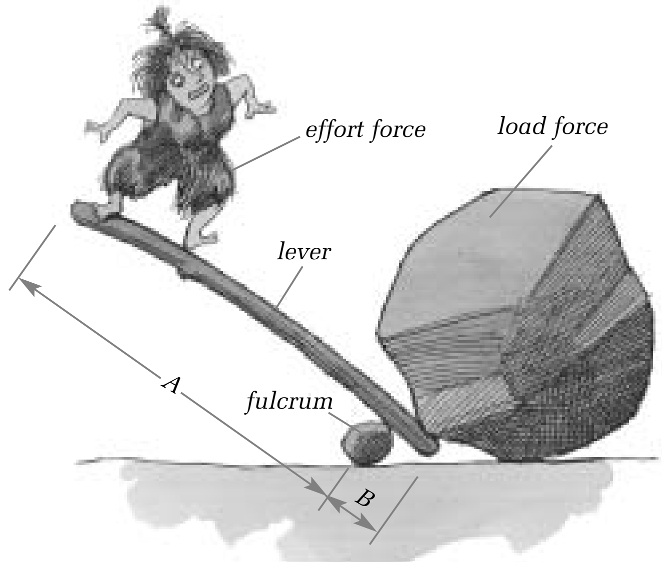


Figure 1.5 The lever is one of the simplest and oldest tools ever used by humans. This drawing shows one way that levers help to move objects. In this example, part A of the lever is seven times longer than part B. This means the force needed to move the object will be one-seventh of the force needed to move the object without using the lever. But look how much farther the person applying the force has to move compared with the distance the rock will move.

Levers can be labelled in three different ways, according to the location of the fulcrum and the load being moved. Figure 1.6 shows the three kinds or classes of levers. A *first class lever* has the fulcrum between the load and the point where the effort is exerted to move the load. A *second class lever* has the load between the effort and the fulcrum. A *third class lever* has the effort between the load and the fulcrum.

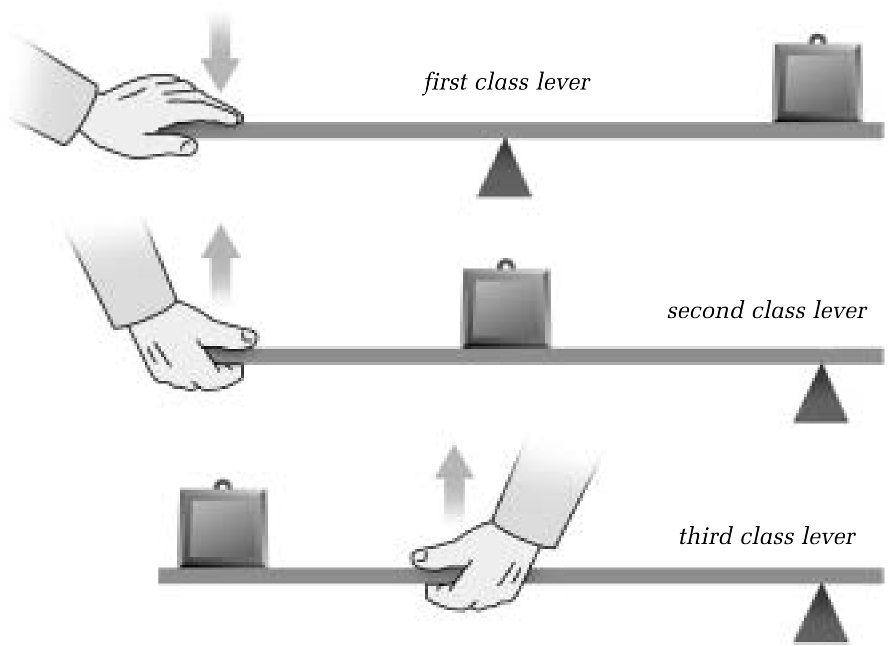


Figure 1.6 Different ways of using a lever

Inclined plane

Imagine that you had to lift a very heavy box from the floor onto a table. You would have to exert a large force to lift it straight up from the floor onto your desk. An **inclined plane** or ramp would make it easier for you to move the box up onto the desk. An inclined plane makes it possible to lift heavy objects using a smaller force. However, you have to exert the force over a larger distance, compared with lifting the object straight up. As well, a ramp is generally useful only for small inclines. The steeper the angle of a ramp, the harder it is to control the motion of an object as it moves up or down the ramp. Examples of inclined planes include loading ramps on buildings and wheelchair access ramps.

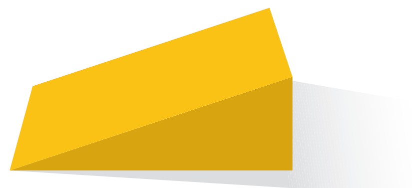
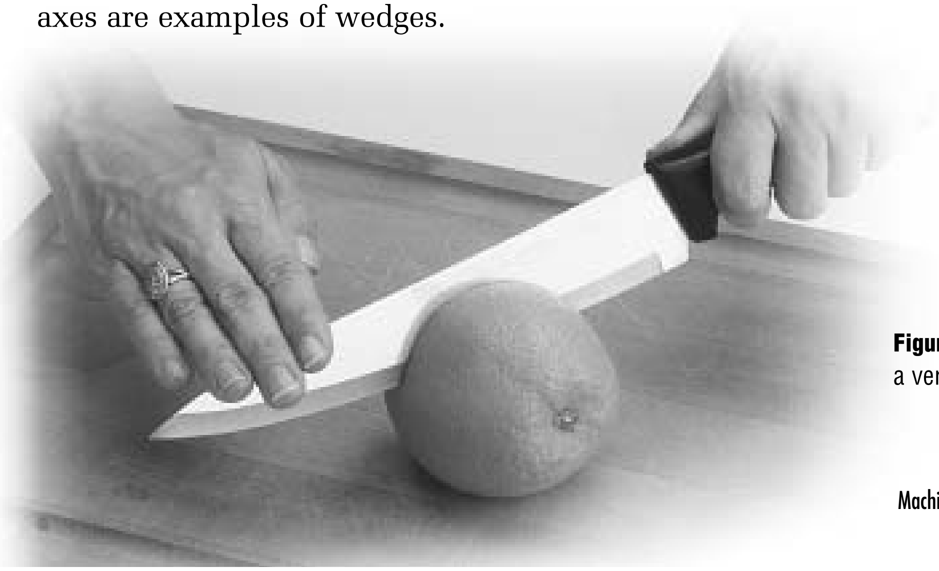


Figure 1.7 An inclined plane or ramp can help move large, heavy objects that are too heavy to lift straight up.

Wedge

A **wedge** is similar in shape to an inclined plane, but it is used in a different way. The wedge machine is forced into an object. By pressing on the wide end of the wedge, you can exert a force on the narrow end so it splits an object apart. The wedge increases the force that you apply on the object. But it moves a greater distance into the object than the split it causes. Unlike the ramp, a wedge can be used only in one direction: to push objects apart. Knives and axes are examples of wedges.



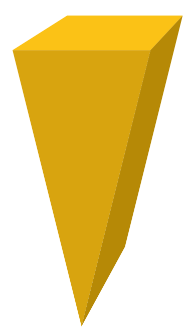


Figure 1.8 A knife blade is a very thin wedge.

Screw

A **screw** is a cylinder with a groove cut in a spiral on the outside. Using a screw helps you increase the force you use. It can penetrate materials using a relatively small force. A screw can also be used for converting rotational (turning) motion to linear motion (motion in a straight line). You saw an example of this earlier in the pictures of the Archimedes screw. Figure 1.9 shows how the screw moves in a spiralling motion. This is the rotational motion. However, the screw is also moving the water along a line from point A to point B. Most screws will move objects very slowly.

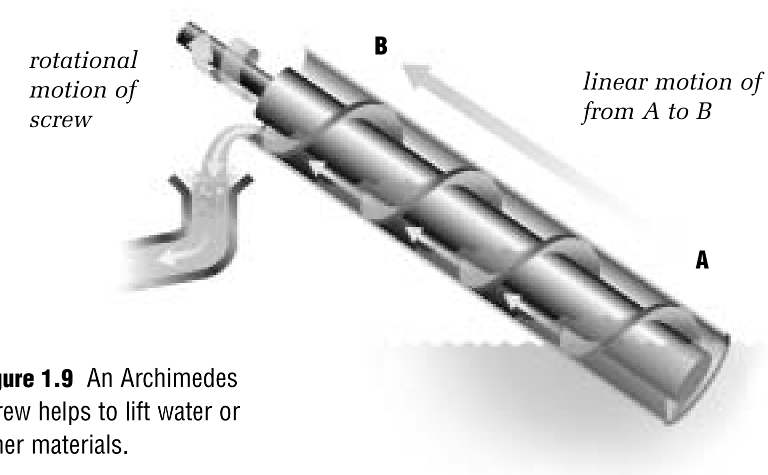


Figure 1.9 An Archimedes screw helps to lift water or other materials.

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Early Tools

Many of the tools used by Canada's earliest inhabitants were simple machines. Using resources available in your library or on the Internet, identify a tool that was used by Aboriginal peoples in Canada before the year 1800. Once you have identified a tool, determine what needs the tool met, and the simple machine(s) it contained.

Pulley

A **pulley** consists of wire, rope, or cable moving on a grooved wheel. Pulleys may be made up of one or many wheels and can be fixed in place or movable. They can be linked together in systems for moving and lifting objects. Pulleys help you lift larger loads than you could lift on your own.

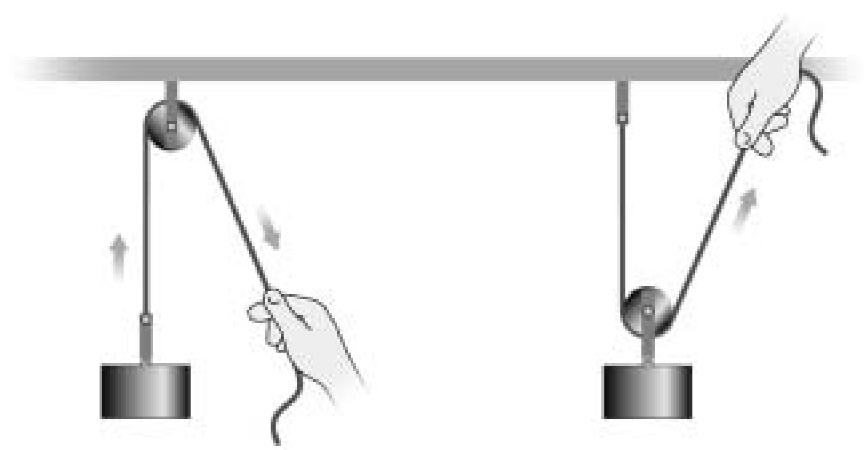


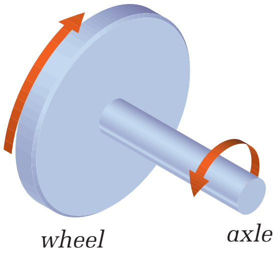
Figure 1.10 Two types of pulleys

Figure 1.11 Pulleys make it possible to lift large, heavy loads.

Wheel and Axle

The **wheel and axle** is a combination of two wheels of different diameters that turn together. A longer motion on the wheel produces a shorter but more powerful motion at the axle. The steering wheel and steering column in a car together form a wheel and axle. That combination is one example of using a wheel and axle to increase the size of a force. The drawback is that you have to turn a greater distance (a larger wheel) to apply the force. A wheel and axle can also be used to increase speed. Wheels on bicycles are examples of using this simple machine to increase speed. The rider exerts a large force to turn the axle, which causes the bicycle's wheel to turn. The rider moves faster on the bicycle than without it.

Figure 1.12 A doorknob is a wheel-and-axle machine. Which part is the wheel and which part is the axle?



Inquiry Activity

The Right Machine for the Job

Before You Start ...

Have you ever tried to lift a very heavy object? Did you need to have another person help you, or maybe you used a lever or a ramp to help you? These devices are both simple machines. In this activity, you will investigate a variety of simple machines and determine which machine is best suited for lifting a mass.

Materials & Equipment

- 30-cm string
- 1-kg mass
- 20-N spring scale
- ramp
- 60-cm string
- pulley system
- metre-stick
- 10-cm string
- pivot or fulcrum

The Question

Which simple machine requires the least amount of force to lift a 1-kg mass?

Procedure

Station 1. Lifting without a Machine

1. Tie a loop at one end of the 30-cm string, so the loop fits over the hook on the spring scale. Tie the other end of the string to the 1-kg mass.
2. Lift the spring scale just until the mass is hanging from the scale. Now slowly raise the load 10 cm. Measure and record the force needed to lift the mass.

Station 2. Lifting with a Ramp

3. Set up the ramp so that the highest point of the ramp is 10 cm above the top of the surface it's sitting on.
4. Place the mass on the bottom of a ramp and attach the loop of string to the spring scale again. With your hand at the top of the ramp, pull the mass steadily up the ramp. Measure and record the force needed to raise the mass.

Figure 1.13 Step 4. Pull the mass steadily up the ramp.

Station 3. Lifting with a Pulley System

5. Tie one end of the 60-cm string to the mass. Place the mass on a table below the pulleys and thread the string between the pulleys.
6. Tie a loop at the loose end of the string and attach the string to the spring scale. Use the pulleys to raise the load 10 cm. Measure and record the force needed to lift the mass.

Figure 1.14 Step 6. Use the pulleys to lift the mass up 10 cm.

Station 4. Lifting with a Lever

7 Place the metre-stick on the fulcrum so that the fulcrum is in the middle of the metre-stick. Hang the mass from one end of the lever. Use the 10-cm piece of string to make a loop and attach the spring scale to the opposite end of the lever. This end of the lever should be far enough above the table or the floor so you can use the spring scale to pull down on it.

8 Pull down the spring scale so the lever raises the mass at the other end. Record the force need to lift the mass.

9 Change the location of the fulcrum under the metre-stick and repeat step 8.

Figure 1.15 Step 7. The metre-stick is now acting as a lever.

Collecting Data

10 Record the force needed to lift the mass in each case.

11 Record your observations of the differences when you changed the position of the fulcrum under the metre-stick.

Analyzing and Interpreting

12 What was the most difficult method of raising the mass? What was the easiest method? Why do you think that is?

13 For the lever (the metre-stick):

a) What effect does the location of the fulcrum have on the force you must use to lift the mass?

b) What effect does the location of the fulcrum have on the distance that your hand moved and the mass moved?

14 What feature of the lever made it easier to lift the load?

15 What change would you make to the ramp to make it even easier to raise the mass to a 10-cm height?

Forming Conclusions

16 Using sentences and diagrams, describe how a simple machine increases the force that you apply to an object. Include the features of the simple machines in this activity as examples.

THE EFFECTS OF SIMPLE MACHINES

Simple machines can be used to obtain one of the effects shown below. Remember that a simple machine can increase the force that you apply, or change the direction of the force, but there is a cost. The force that you apply has to move farther than the load does.

1 *Changing the direction of a force (for example, a pulley on a flagpole)*

Figure 1.16 To raise the flag, you pull down. The pulley changes your downward pull to an upward pull on the flag.

2 *Multiplying force (for example, a screwdriver)*

Figure 1.17 A small force on the handle of the screwdriver becomes a large force in the shaft. This large force can then be used to undo screws that would be impossible to remove with your fingers alone.

3 *Increasing or decreasing speed (for example, scissors)*

Figure 1.18 To cut, you move the scissors' handles together. The scissors' blades cut the paper more quickly than you move the handles together. And they cut farther than the distance the handles move. Try it and see!

4 *Transferring force (for example, a staple remover)*

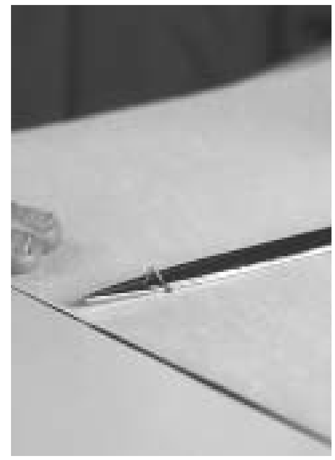


Figure 1.19 A lever like this staple remover transfers force to the object being moved. In this case, it is transferring the force from the student to the staple.

CHECK AND REFLECT

Figure 1.20 Question 4

1. Identify which simple machines you would use in each of the following situations:
   a) digging a deep hole
   b) moving a heavy rock from one side of your yard to the other
2. a) Give examples of energy sources used for modern machines, such as cars and sewing machines.
   b) Are the energy sources in question 2a) the same as those used in machines before the 1900s? Explain your answer.
3. When a simple machine increases the force you exert, what other factor changes?
4. One of the most important tools for pioneers in Canada was the axe. What two simple machines make up the axe?

1.2 The Complex Machine—A Mechanical Team

As time passed, people began living in larger communities. They needed to find ways to build larger buildings, provide running water, and develop transportation systems for moving people and goods. To do these and other tasks, they developed ever more complicated machines. They also found new ways to power these machines.

Within the last two centuries, scientists, engineers, and other inventors have developed machines that use sources of energy such as coal, oil, and electricity. These large supplies of energy, combined with new materials and new technologies, caused an industrial revolution. Large factories were now possible.

The first factories used powerful new machines to mass-produce goods. The newly invented steam engine transported these goods across countries in record time. People now had access to more food, clothing, tools, and raw materials than they ever had before, and their standard of living improved.

The development of new technologies has continued at a tremendous rate. Today we are almost completely dependent on machines. Think of the things that you enjoy doing that depend on a machine for delivering energy or for moving objects. Can you imagine how your life would change if you could *not* use machines?

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The Changing Bicycle
The bicycle is one of the most efficient machines ever invented to translate human energy into motion. The penny-farthing shown here was an early bicycle design. It had only levers for steering, and the wheel and axle for moving.

Figure 1.21 The invention of the steam engine led to the development of trains. Trains could travel faster than horses and haul much larger loads.

Complex Machines

Most of the devices that we use today are made up of several simple machines. These devices are called **complex machines**. A complex machine is a system in which simple machines all work together. A **system** is a group of parts that work together to perform a function. For example, the bicycle in Figure 1.22 is a system for moving a person.

Within the bicycle are groups of parts that perform specific functions, such as braking or steering. These groups of parts are called **subsystems**. The subsystems in a complex machine have just one function each. A subsystem usually contains a simple machine. All the subsystems work together to complete the task that the complex machine was designed to do.

The bicycle is a good example of a complex machine. Several subsystems work together to move you forward at different speeds, allow you to turn, and help you stop. Each subsystem uses a simple machine to help you do the task more easily. Figure 1.22 shows the major subsystems in a typical bicycle.

Figure 1.22 A bicycle is a complex machine made up of simple machines that work together. The whole bicycle is a system, made up of many subsystems.

Give it a **TRY** — ACTIVITY

ANALYZING A MECHANICAL DEVICE

You are surrounded by a wide variety of machines, both big and small, in your daily life. Now you have an opportunity to look inside one of those machines and see how it works. You can use the one illustrated here or a device provided by your teacher.

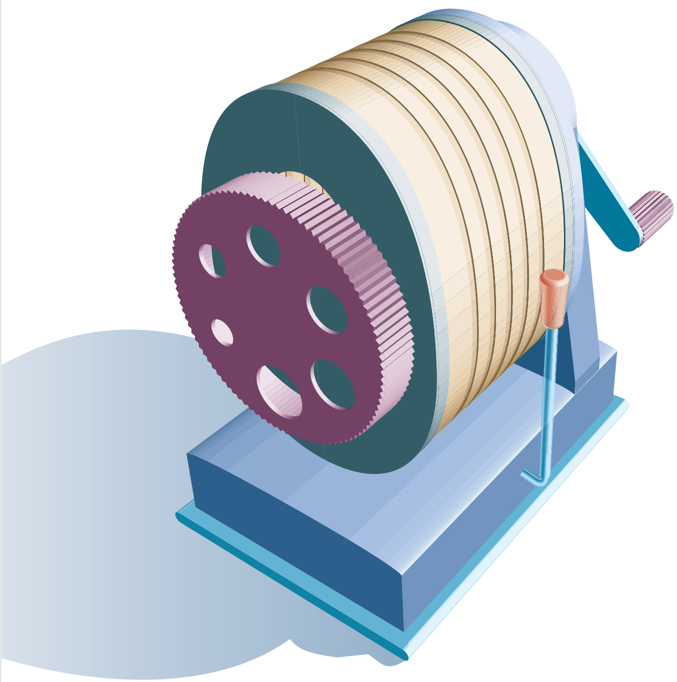


Figure 1.23 What is the function of this device?

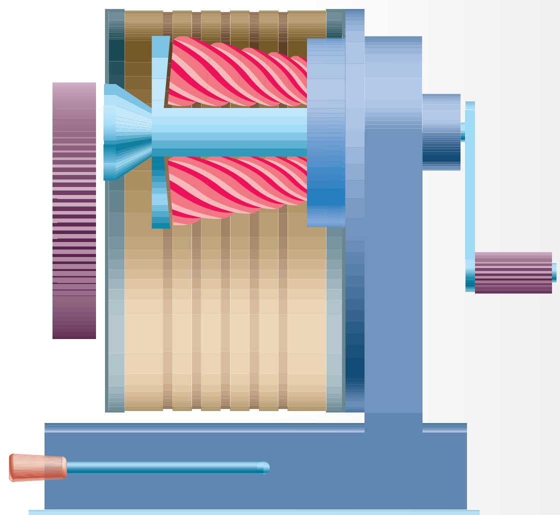
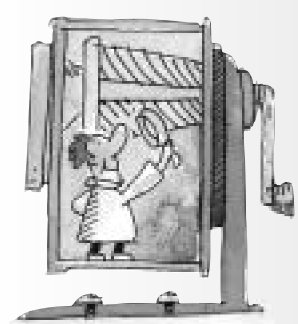


Figure 1.24 How does each subsystem contribute to the device's function?

Work with your partner to answer the following questions.

- What is the overall function of the device?
- How many individual subsystems can you identify in the device? Describe how each one contributes to the device's function.
- Do any of these subsystems contain a simple machine? If so, describe them.

Use a flowchart or diagrams to show how all the subsystems work together to make the device function.



Subsystems That Transfer Forces

Some of the subsystems in complex machines that produce motion play a role in the transfer of energy or force. In mechanical devices, these subsystems are called linkages and transmissions. Gears are often an important part of these subsystems.

Linkages

A complex machine moves an object by transferring energy from an energy source to the object. For a bicycle, you are the energy source. The bicycle's wheels are the objects that you must turn to make the bicycle move. The **linkage** is the part that transfers your energy from the pedals to the back wheel. In a bicycle, the chain is that linkage.

Many machines use high-tension belts instead of chains to rotate objects. You may have seen a belt used as a linkage in older car engines. This is the fan belt, which transfers energy from the engine to spin the cooling fan. The fan moves air through the radiator to keep the engine from overheating.

Chains or belts form a direct link between two separated wheels, so that when one turns, the other will turn in the same direction. If one wheel is larger, it will rotate more slowly, but with a larger force, than the smaller wheel. Chains have less chance of slipping than a belt, but belts are more flexible.

Figure 1.25 In a bicycle, the chain is the linkage that drives the gearwheels. When you shift gears, you move the chain from the larger gearwheel to the smaller ones or vice versa.

Transmissions

Most machines that move objects are more complex than a bicycle. They usually move much larger loads than just one person. These machines use a special type of linkage called a **transmission** to transfer the energy from the engine to the wheels. A transmission contains a number of different gears. This allows the operator to apply a large force to move objects slowly, or a smaller force to move objects quickly.

Transmissions are similar to the gears on a bicycle, except that they are designed to transfer much larger forces. In a car, for example, the driver can select a low gear to start the car moving, and then change to higher gears when driving on a highway.

In a low gear, the transmission connects a small wheel to a larger wheel, so the wheels rotate more slowly than the engine does. This increases the amount of power but reduces the car's speed. In a high gear, the transmission connects a large wheel to a smaller wheel, so the wheels rotate faster than the engine. This reduces the amount of power but increases the car's speed.

*re***SEARCH**

Automatic and Manual Transmissions

What is the difference between an automatic transmission and a manual transmission in a car or truck? Which one is better? Which one costs more? Why?

GEARS

Gears are essential components of most mechanical systems. They consist of a pair of wheels that have teeth that interlink. When they rotate together, one gearwheel transfers turning motion and force to the other. The larger gearwheel rotates more slowly than the smaller gearwheel, but it rotates with a greater force. Gears can be used to increase or decrease speed in a machine. Both cars and bicycles use gears to change speed. Gears can also be used to change the direction of motion of a mechanical device like the eggbeater in Figure 1.26.

Figure 1.26 The gears on an eggbeater change the vertical motion of your cranking to the horizontal motion of the beaters.

Inquiry Activity

BICYCLE GEARS

Materials & Equipment

- multi-geared bicycle
- spring scale
- metre-stick or measuring tape

Caution!
Turn the pedal slowly and keep your fingers away from the wheel spokes and gears.

Figure 1.27 The gears on a bicycle are divided between the front and the rear.

The Question

What are the differences among three different gears on a bicycle?

Procedure

1. With your group, observe the two sets of gears on the bicycle—front and rear. The rear set has more gears than the front one does. The gears are made up of flat, toothed disks called sprockets.
2. As a group, decide which three gears you will study. Count the number of teeth on the front and rear sprockets for each gear. Record this information in your table.
3. Measure the distance from the centre of the rear wheel to the edge of the tire. This is the radius of the rear wheel.
4. Measure the distance from the centre of the front sprocket to the outer-most point of the pedal. This is the radius of the circle that the pedal makes when it moves.
5. Attach a spring scale to the pedal. Apply just enough constant force to turn the pedal for one complete revolution. How much force is required to turn the pedal one turn? Record your result.
6. How many times did the back wheel turn for one turn of the pedal? Record your result.
7. Repeat steps 5 and 6 for the other two gears. Record your results.

Collecting Data

8 Record your observations in your notebook in a table like the one below.

Gear	Front sprocket: No. of teeth	Rear sprocket: No. of teeth	Radius of rear wheel	Radius of pedal	Force needed for 1 pedal turn	No. of back wheel turns
Lowest gear						
Middle gear						
Highest gear						

Analyzing and Interpreting

9 For each gear, divide the number of teeth on the front sprocket by the number of teeth on the rear sprocket. Record your results in your notebook.

10 Find the circumference of the circle the pedal makes when it goes through one turn. To do this, multiply the radius of the pedal's circle by 2π or 6.28. This is the linear distance the pedal travels in one turn. Record your result in your notebook.

11 Find the circumference of the rear wheel by multiplying the wheel's radius by 2π or 6.28. This is the linear distance the wheel travels in one turn. Record your result in your notebook.

12 For each gear, determine how far the rear wheel travelled with one complete turn of the pedal. This can be calculated by multiplying the circumference of

How Gears Work

Almost any device that contains spinning parts uses gears. If you look inside a VCR, you'll see gears. You may have an electric meter with a clear plastic cover on the outside of your house. Take a look in it and you will see many different sizes of gears.

Gears are important in mechanical systems because they control the transfer of energy in the system. For example, in a bicycle, they control the transfer of energy from the rider to the wheels. They allow the rider to control and change the speed at which the wheels turn. In a car or other motorized vehicle, they control the transfer of energy from the engine to the wheels.

Gear wheels work together in gear trains of two or more wheels, like the one shown in Figure 1.28. The gear that has a force applied to it from outside the gear train is the driving gear. It then applies a force to the other gear, called the driven gear.

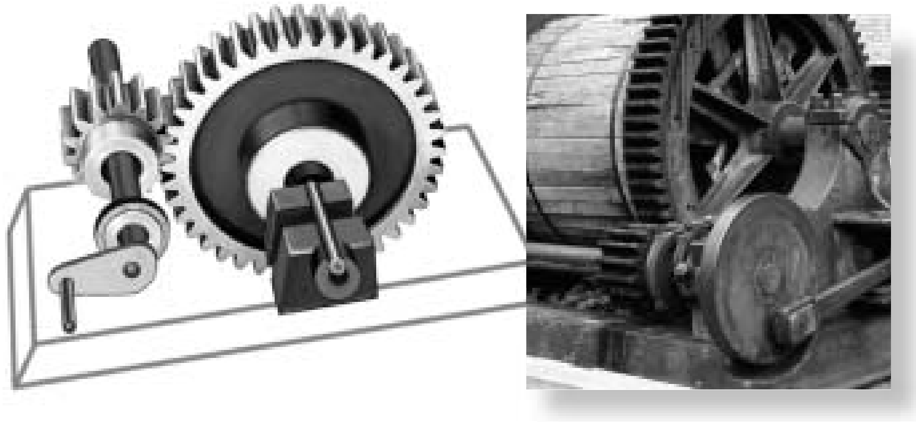


Figure 1.28 A gear train

How Gears Affect Speed

If the driving gear is larger than the driven gear, the turning speed in the system increases. When you rotate the large gear once, it rotates the smaller gear several times. Think about the gears in an eggbeater like the one shown in Figure 1.26. When you turn the crank, you rotate the large gear, which is the driving gear. It rotates the smaller gears attached to the beaters through four complete turns. This makes the beaters move much faster than the handle, so you can beat the eggs more quickly.

Gears like these that increase the speed of rotation in a device are called multiplying gears. Reducing gears decrease the turning speed in a device. In reducing gears, the driving gear is smaller and has fewer teeth than the driven gear, as shown in Figure 1.29.

In a bicycle, gear wheels do not mesh directly with each other. They are joined by the chain, which provides the linkage between the different sizes of gear wheels. When you shift gears, you move the chain from one gear wheel to another. In this way, you can change how fast you go when you pedal.

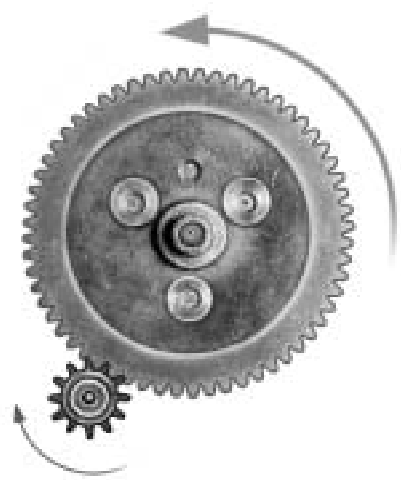


Figure 1.29 Reducing gears decrease turning speed in a device.

Check and Reflect

1. What is the difference between a simple and a complex machine?
2. What improvements have been made to bicycle designs over the last century?
3. a) Your body is made up of several simple machines that help you move. Identify three parts of your body that act as simple machines. Identify the kind of machine for each one and explain what it does.

   b) What parts of your body act as linkages?
4. Picture yourself riding a bicycle in a race. Describe how energy is transferred from your body to the bicycle wheels.
5. What are gears? How are they used?

Try This at Home

Activity

How Many Machines Are in Your Home?

You have lived with machines all of your life, so you may not be aware of how many machines you depend on for comfort, security, and convenience. The machines you have in your home help you and your family do many jobs—even when you're not there!

- Make a list of all the machines that you can think of in and around your home. Some machines may not be obvious. Remember that a machine is any device that moves an object or transfers energy.
- Next to each machine in your list, describe the task that the machine performs.
- Identify the source of energy for each machine in your list. What source of energy do most of the machines use?
- On a typical school day, which of these machines do you use or does someone use to help you? Write a short story describing what your day would be like if you didn't have any of these machines. Would you be able to do the same things? How would you do them?

Assess Your Learning

1. a) How can you determine if a device is a simple or a complex machine?
   b) Use your answer to question (a) to determine if your body is a simple or a complex machine.
2. Why does a car have a transmission but a bicycle doesn't?
3. Explain how using levers, gears, or other ways of linking components improves the operation of the following devices:
   a) scissors
   b) bicycle
   c) eggbeater
4. Describe three jobs that depend on the use of machines. List the type of machine(s) used with each job.
5. Look at the machine in Figure 1.30, and then answer the questions below.
   a) Is this device a simple or complex machine? Explain your answer.
   b) What do you think the source of energy is for this machine? How do you know?
   c) Draw a simple sketch of a similar machine in your notebook. On your sketch, show how energy is transferred through the machine. Label any levers, gears, or belt drives.
   d) Do you think this device could work in real life? Why or why not?

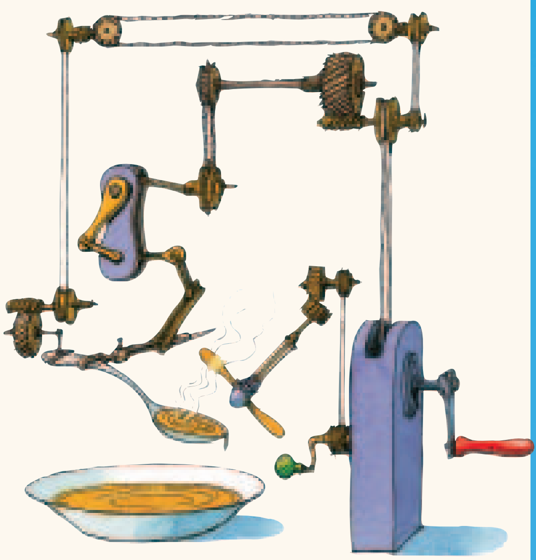


Figure 1.30 Question 5

Focus On SCIENCE AND TECHNOLOGY

The products of technology are devices, systems, and processes that meet given needs and wants. For example, a CD player is a system of devices that work together to provide us with entertainment or educational information. Think back to the information you learned and the activities you did in this section.

1. Describe two devices or systems that you read about in this section.
2. What needs were these devices invented to meet?
3. Identify any other devices or systems that you know about that can meet these same needs. Why do you think more than one device or system exists to meet the same need?

2.0

An understanding of mechanical advantage and work helps in determining the efficiency of machines.

Key Concepts

In this section, you will learn about the following key concepts:

- mechanical advantage, speed ratios, and force ratios
- mechanical advantage and hydraulics
- measurement of work in joules

Learning Outcomes

When you have completed this section, you will be able to:

- determine the mechanical advantage and the speed ratio of a mechanical device
- modify a model mechanical system to achieve a given mechanical advantage
- identify the reason for differences between theoretical and actual mechanical advantages
- identify work input and output for a simple machine or mechanical system
- describe how hydraulic pressure can create a mechanical advantage

The size of sailboats used to be limited by the size and number of sails that sailors could raise on their own. Once pulley systems were introduced, sailors could lift much larger sails. Larger sails meant bigger boats. Bigger boats were able to carry more people and cargo—and travel farther than ever before. An understanding of simple and complex machines opened up the world for exploration.

By understanding and using simple and complex machines, people have created today's world of machines. In this section, you will learn how a machine can increase a force, and how it affects the speed of an object.

The scientific definition of work is another important concept in understanding machines. Examples in this section will help you develop an understanding of work.

You will also explore more hydraulic machines. You will have an opportunity to build your own simple hydraulic system.

For Web links relating to 2.0, visit www.pearsoned.ca/scienceinaction

2.1 Machines Make Work Easier

Figure 2.1 A machine can help us do things we wouldn't be able to do on our own.

Imagine that you are on a car trip with friends, far from the nearest city, and suddenly the car gets a flat tire. The driver opens the trunk to take out the spare tire—but there is no car jack! What can you do? The car is too heavy for anyone to lift. The answer is to use a machine—one that you can assemble quickly from available materials. A lever would work. One person can lift a corner of a car using a long lever, such as a sturdy log placed securely on a large rock.

*info***BIT**

Winding Mountain Roads

Roads across the open Prairies extend in straight lines for long distances or bend in gentle curves. Roads that have to climb steep hills or mountains bend sharply back and forth. This style of road building is used wherever the slope is too steep for vehicles to drive straight up. Vehicles don't have enough power to climb a steep slope, so each section of road is built so that it raises the vehicle a little higher. After a sharp turn, called a switchback, vehicles can climb higher again. So a mountain road is actually a series of simple machines—ramps that make it easier for vehicles to climb.

*info***BIT**

The Newton

The newton (N) is the unit for measuring force. It is named after Sir Isaac Newton, the great scientist who studied force and motion. One newton is equal to the amount of force exerted by Earth's gravity on a mass of about 100 g (e.g., an egg, an orange).

Mechanical Advantage

A machine can make work easier by increasing the amount of force that you exert on an object. In the car example on the previous page, the lever increased the force that the person could exert on the car. A person alone could not exert enough force to lift a car. But using a machine—the lever—made it possible. The scientific explanation is that the lever provided mechanical advantage.

The **mechanical advantage** of a machine is the amount by which a machine can multiply a force. The force applied to the machine is called the **input force.** The force the machine applies to the object is called the **output force**. In the car example in Figure 2.1, the person applies an input force to the long end of the lever. The short end of the lever applies the output force to the car. The output force is much larger than the input force, and the car is lifted. Input and output forces are measured in newtons.

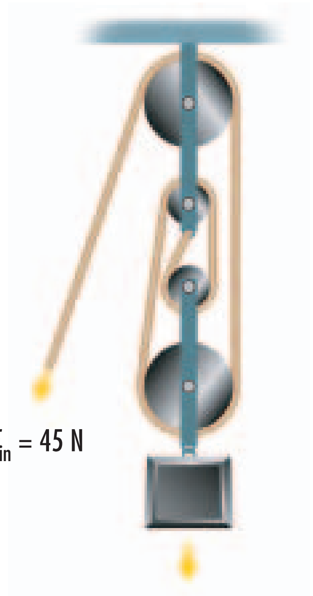
Calculating Mechanical Advantage

You can calculate the mechanical advantage of a machine if you know the input and output forces. The mechanical advantage equals the output force divided by the input force.

$$\text{Mechanical Advantage (MA)} = \frac{\text{Output force}}{\text{Input force}}$$

The mechanical advantage is actually a ratio of forces in the mechanical device. For this reason, mechanical advantage is also called the *force ratio* of the machine.

Here is an example of how to calculate mechanical advantage. This example is shown in Figure 2.2. It takes 45 N to lift a 180-N box with a pulley. (If you lifted it by yourself, you would have to use 180 N.) So the pulley has a mechanical advantage of 4 (180 ÷ 45). This calculation is also shown below. The more a machine multiplies force, the greater its mechanical advantage.



F_{in} = 45 N

F_{out} = 180 N

Figure 2.2 This pulley has a mechanical advantage of 4. It multiplies the force you use to pull on it by 4. This enables you to lift a much heavier load than you could on your own, without the pulley.

$$\text{Mechanical Advantage} = \frac{\text{Output force}}{\text{Input force}}$$

or

$$MA = \frac{F_{\text{output}}}{F_{\text{input}}} = \frac{180\text{ N}}{45\text{ N}} = 4$$

Where F = Force in newtons (N)

Speed Ratio

Calculating the speed ratio is another way of analyzing how machines work. *Speed* measures the distance an object travels in a given amount of time. A measure of how the speed of the object is affected by a machine is called the **speed ratio**. The speed ratio is calculated by dividing the *input distance* by the *output distance*.

$$\text{Speed Ratio (SR)} = \frac{\text{Input distance}}{\text{Output distance}}$$

Figure 2.3 shows the input distance and output distance for the same pulley that was used in Figure 2.2. The calculation of this pulley's speed ratio is shown below.

$$\text{Speed Ratio} = \frac{\text{Input distance}}{\text{Output distance}}$$

$$SR = \frac{d_{input}}{d_{output}}$$

Where d = distance

$$SR = \frac{4\ \text{m}}{1\ \text{m}}$$

$$SR = 4$$

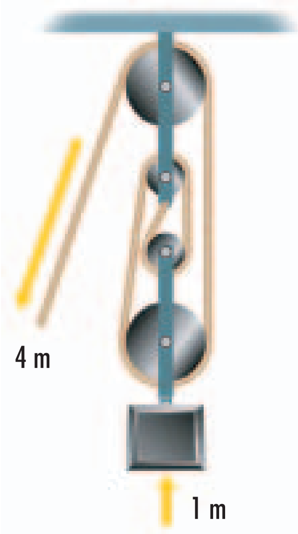


Figure 2.3 This pulley has a speed ratio of 4.

The speed ratio of 4 means that the part of the pulley where you apply the input force moves four times faster than the part where the output force is—the load that you are lifting.

Using these formulas, you can calculate mechanical advantage and speed ratio for any device. Here is an example.

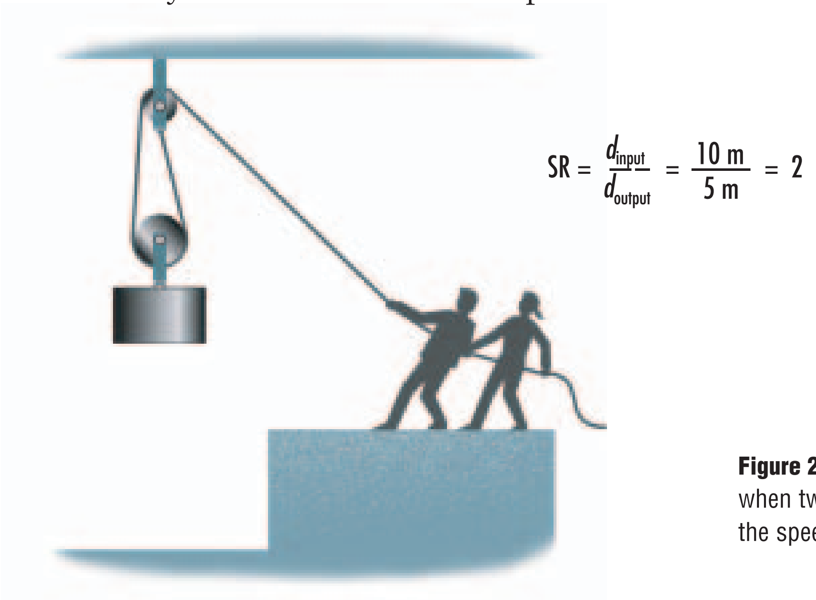


Figure 2.4 A pulley system lifts a load 5 m when two people pull the rope 10 m. What is the speed ratio of the pulley system?

LESS FORCE BUT GREATER DISTANCE

The examples and calculations you've done for speed ratio demonstrate you do not get "something for nothing" when you use a machine. The pulley system in Figures 2.2 and 2.3 multiplies the force you exert, which is an advantage. But in using the pulley, you have to pull much farther than the load actually moves.

You can also see this effect if you use a ramp to help you lift a large object. Figure 2.5 compares two ramps used to raise the same load to the same height. Which ramp has the greater mechanical advantage? Which ramp is longer (which means you have to push the load farther)? What is the speed ratio of the ramp?

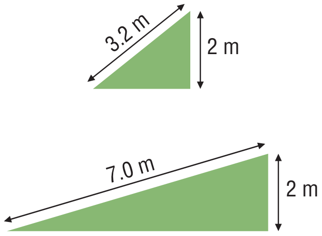


Figure 2.5 What factors affect the mechanical advantage of a ramp? What factors affect the speed ratio?

A MECHANICAL ADVANTAGE LESS THAN 1

So far, we have looked only at examples where the mechanical advantage of a device is greater than 1. In those cases, the machine is multiplying the input force to create a larger output force. But sometimes the mechanical advantage of a mechanical device may be less than 1. Does this mean the machine isn't useful? No, it means that the machine is useful for tasks that don't require a large output force.

Think about the bicycle again. It has a mechanical advantage less than 1. For example, a cyclist may apply an input force of 650 N to the pedals. Through the bicycle's linkages, this results in an output force of 72 N. Recall the formula for calculating mechanical advantage: MA = Output force ÷ Input force = 72 ÷ 650 = 0.1. The mechanical advantage of the bicycle is 0.1.

The output force causes the bicycle to move much faster than the rider would walk. So even though the mechanical advantage is less than 1, the bicycle is still a very useful machine.

Figure 2.6 The mechanical advantage of a bicycle is less than 1. Do you think the speed ratio of a bicycle would be less than or greater than 1?

Problem Solving Activity

Building a Mechanical System

Recognize a Need

Lifting large loads sometimes requires a combination of simple machines. For example, Figure 2.7 shows a boat being hauled out of the water and onto a trailer.

The Problem

Use 2 simple machines to create a mechanical system to raise a 1-kg mass 30 cm with the greatest possible mechanical advantage.

Criteria for Success

For the construction of your mechanical system to be successful, you must meet the following criteria:

- Your mechanical system must consist of at least 2 simple machines.
- It must raise a 1-kg mass at least 30 cm.
- You must use a spring scale to accurately measure the force needed to raise the 1-kg mass with the mechanical system.
- You must achieve the same mechanical advantage with this mechanical system at least twice.

Materials & Equipment

- pulleys
- ramps
- material for levers (lengths of wood)
- string
- plastic gears
- wheel and axle
- screws or adhesives
- spring scale

Figure 2.7 The ramp is an inclined plane that helps to lift the boat onto the trailer. The winch is a wheel and axle with a cable on it. It pulls the boat up the ramp and onto the trailer.

Brainstorm Ideas

TOOLBOX

1 You will be working in teams. As a team, brainstorm possible solutions to the problem. Once you have several solutions, choose the one you think will work the best to meet the criteria listed above.

Build a Mechanical System

2 Create a plan of how you will build your mechanical system. Include a diagram of the mechanical system and a list of materials you will need. Show your plan to your teacher for approval.

3 Assemble your materials and build your mechanical system. Remember that you may need to modify or change your design as you build your mechanical system. Make sure to note any changes you make to your original design.

Test and Evaluate

4 When you have built your mechanical system, test it to see if it meets the criteria. After your test, you may need to make some changes and retest it.

Communicate

5 What was the highest mechanical advantage you were able to achieve?

6 Look at your classmates' mechanical systems. Identify one modification that you could make to your system to improve it.

7 Calculate the speed ratio for your mechanical system. Is it the same as mechanical advantage? If not, why do you think there is a difference?

Comparing Real Mechanical Advantage and Speed Ratio

In Figures 2.2 and 2.3, the calculated mechanical advantage and speed ratio for the pulley system were the same. In real situations, however, they may not be. Here's an example.

A group of students set up the mechanical system shown in Figure 2.8. They measured the length of the ramp and the distance from the desktop to the highest point. With this information, they calculated that the speed ratio for the system should be 2. Having seen the example of the pulley system earlier in this section, they assumed that the mechanical advantage would also be 2.

They then measured the mechanical advantage by using a spring scale to pull the load up the ramp. Using the measured force, they calculated the mechanical advantage. It was less than 2. Why wasn't the mechanical advantage the same as the speed ratio in their experiment?

Figure 2.8 The measured mechanical advantage of this system was less than the speed ratio when the students tested it.

The Effect of Friction

The difference between the theoretical and the real value of the mechanical advantage was the result of friction. Recall from earlier studies that **friction** is a force that opposes motion. Friction is caused by the surface roughness of materials. A rough surface creates more friction than a smooth one. Even surfaces that we think are very smooth are uneven if seen under a magnifying glass or microscope.

Friction can be an important factor in a mechanical system because it opposes motion. This means that extra force is needed to overcome friction whenever you move an object. Think about pushing a box up a ramp. The friction created by the box rubbing against the ramp means you have to push harder than you would if there was no friction. You have to exert a stronger force, so the mechanical advantage of your ramp is less than it would be under ideal conditions, that is, without friction.

The mechanical advantage of a device is affected by friction but the speed ratio is not. Recall that speed ratio is the input distance divided by the output distance. The distance the box is pushed in our ramp example is not changed by friction, so the speed ratio stays the same. The speed ratio represents the *ideal mechanical advantage* of a machine, as if friction did not exist.

Friction also must be considered in a mechanical system because it creates heat. This heat comes from the two surfaces rubbing against each other. If this heat isn't released, it can cause problems in a system. Special fans and lubricants are used to reduce the effect of heat in a system.

Efficiency

Friction affects the mechanical advantage of a mechanical device, so it also affects its efficiency. **Efficiency** is a measurement of how well a machine or device uses energy.

Recall from section 1.0 that early machines used people or animals as energy sources. Later, water, oil, gas, and electricity provided energy for machines. Any machine, such as a pulley lifting an object, loses some energy as it operates. Usually the energy is lost to heat because of friction. We say it is "lost" because it isn't being used directly for the pulley's task of lifting. It becomes heat, which is not needed or wanted for the task.

The more energy that is lost, the less efficient a machine is. Efficiency is calculated as a percentage. So a machine that is 40% efficient loses more energy than one that is 70% efficient. You can calculate the efficiency of a machine by dividing its mechanical advantage by its speed ratio and multiplying the result by 100. For example, a pulley has a speed ratio of 3 and a mechanical advantage of 2.

$$\text{Efficiency} = \frac{\text{Mechanical Advantage}}{\text{Speed Ratio}} \times 100$$

$$\text{Efficiency (\%)} = \frac{\text{MA}}{\text{SR}} \times 100 = \frac{2}{3} \times 100 = 66.67\%$$

reSEARCH

Designing the Best Transmission

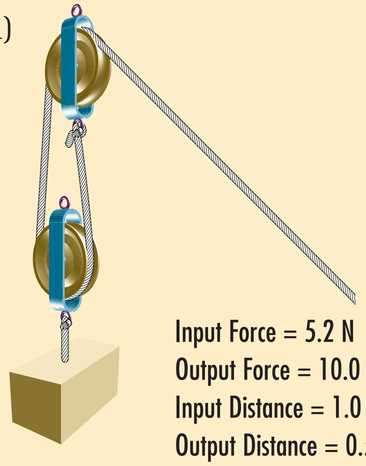
Cars and trucks are designed to handle different sizes of loads and travel in different terrain. Use the Internet or your library to research their different transmissions. How do the mechanical advantage and speed ratio compare for the two different types of vehicles?

In complex machines, the many subsystems are each affected by friction and other factors. Because of this, complex machines are often very inefficient. For example, a typical car engine has an efficiency of only about 15%. That means that 85% of the energy from the gasoline is not used to move the car. Most of it ends up as heat, which is not needed to make the car run. In fact, overheating (too much heat) in a car engine can be a problem.

Check and Reflect

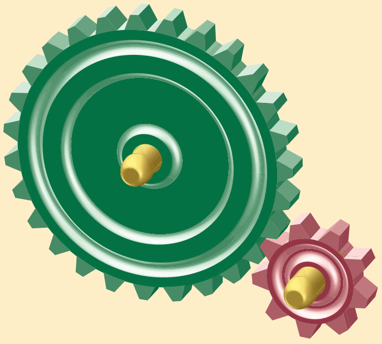
1. Describe how you would measure the mechanical advantage of a bicycle.
2. It takes 350 N of force on the handle of a jack in order to lift a car. It takes 15 000 N of force to lift the car off the ground. Calculate the mechanical advantage of a jack.
3. Calculate the mechanical advantage and the speed ratio for each of the following mechanical devices.

a)



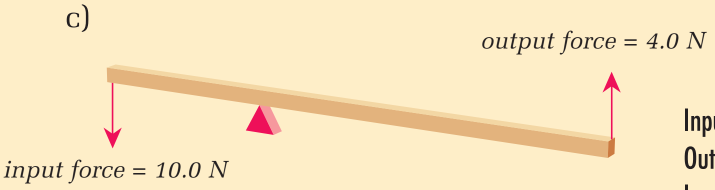
Input Force = 5.2 N
Output Force = 10.0 N
Input Distance = 1.0 m
Output Distance = 0.5 m

b)



Input Force = 7.0 N
Output Force = 20.0 N
Input Distance = 30.0 cm
Output Distance = 10.0 cm

c)



Input Force = 10.0 N
Output Force = 4.0 N
Input Distance = 0.4 m
Output Distance = 0.8 m

4. What is the efficiency of each device in question 3?
5. Why are machines never 100% efficient?

2.2 The Science of Work

You are out with some friends throwing around a Frisbee. You might think it's all play, but you're actually doing work. Later you go home and sit at a table doing homework. You read a page in a science textbook and think about how you will summarize it. You may feel like you are doing work, but according to the scientific definition of work, you aren't.

What does a scientist mean by the word "work"? Look at the photos in Figure 2.9. They all show people and machines doing work, in the scientific sense. Working with a partner, read the captions and try to determine what all these photos have in common. Using that information, develop your own definition of work. Include with your definition a suggestion for how to measure the work done by a person or a machine. Revise your definition as you work through this subsection.

*info***BIT**

How Much Work Does It Take?

A 75-kg person does about 406 455 J of work in climbing to the top of the CN Tower in Toronto. A 1-g bee would do about the same amount of work in flying 42 km.

Figure 2.9a) This student has to exert a force on this microscope to lift it up onto the shelf.

Figure 2.9c) This batter is exerting a force to send the ball flying.

Figure 2.9b) This snowplow is exerting a force on this pile of snow to push it out of the way.

The Meaning of Work

The main difference between how we usually think of work and the scientific definition of work is movement. In the scientific sense, **work** is done when a force acts on an object to make the object move. Look again at the photos in Figure 2.9. In Figure 2.9a) the student is exerting a force directly on the microscope to move it. He is doing work on the microscope. In Figure 2.9b), the driver of the snowplow is using the plow to exert a force on the pile of snow to move it. The snowplow is doing work on the pile of snow. In Figure 2.9c), the person is using the bat to exert a force on the baseball. The bat is doing work on the ball.

It's important to remember that movement is needed before you can say that work has been done. In Figure 2.9a), the student lifted the microscope onto the shelf. What if he just stayed in place holding the microscope? The microscope feels heavy because of the force of gravity pulling on it. He probably feels like he's working to prevent it from falling. However, as long as he just stays there without moving, he is not doing work.

In Figure 2.10, these people are trying to push the car out of the sand. They are exerting a strong force on the car. But if the car doesn't move, they aren't doing any work at all, according to the scientific definition of work.

Figure 2.10 These people are trying as hard as they can to push this car out of the sand. But if the car doesn't move, they are not doing work.

Calculating Work

Work can be calculated using the equation $W = F \times d$ where F is the force exerted on an object and d is the distance the object moves because of the force. Force is measured in newtons and distance is measured in metres. The amount of work done depends on two things:

- the amount of force exerted on the object
- the distance the object moved in the direction of the applied force

If you lifted your chair onto your desk, how much work would you do? Assume that you have to exert a force of 50 N to lift the chair and your desk is 0.4 m high.

$W = F \times d$

$W = 50\ \text{N} \times 0.4\ \text{m} = 20\ \text{N·m}$

You did 20 N·m of work. The newton·metre is called a joule, named after the English scientist James Joule. Joule was especially interested in the relationship between work and energy. It's not surprising then that the joule is also the unit used in measuring energy.

Figure 2.11 If you lift the chair or push it along the floor, you are doing work. But if you just hold the chair up without moving, you are not doing any work.

Energy and Work

Energy and work are closely related because without energy, there would be no work. When you ride your bicycle, you exert a force on the pedals. The chain transfers that force to the wheels, causing them to move. Your energy is used to provide the force that drives the pedals that move the wheels of your bike. Work is being done because the force you apply to the pedals causes the bicycle to move.

In a car, the energy to drive the wheels comes from gasoline. An energy source (the gasoline) provides the force that makes the work (the car moving) possible. The machine transfers energy from the energy source to the object, causing the object to move. Earlier you learned that machines help us do work. They help us do work by transferring energy.

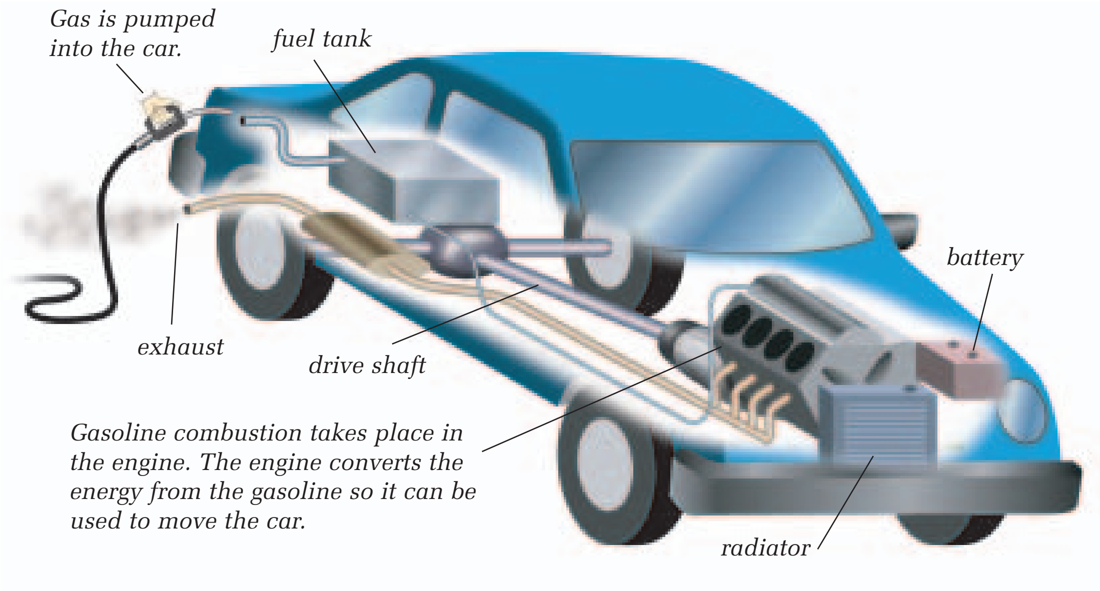


Figure 2.12 Gasoline is the energy source for a car. The combustion of the gasoline causes pistons to move. The pistons are linked to the transmission. Subsystems within the transmission, such as the drive shaft, work together to cause the car's wheels to move. When the car moves, work is done by the whole system. But within the system, work is being done by every part that moves when a force is applied to it.

Work and Machines

In subsection 1.1, you learned about the different kinds of simple machines and how they can help us do work. But using a machine does not mean that less work is done. You use the machine so you don't have to exert as much force. But you still do the same amount of work.

Figure 2.13 The ramp makes it possible for Serena to use less force in helping Kim to the top of the ramp. A much greater force would be needed to lift Kim straight up from the ground to the height of the top of the ramp.

To show why work done with a machine is the same as work done without it, you can calculate work input and work output. The work input is the work needed to use or operate the machine. Look at Figure 2.13. In this example, the work input is the work done by the student using the machine—the inclined plane—to lift the student in the wheelchair. In this case, the pushing student exerts a force of 320 N for a distance of 5 m. You can use the formula for work to calculate the work input:

$$W_{input} = F_{input} \times d_{output}$$

$$\text{Work}_{\text{input}} = 320 \text{ N} \times 5 \text{ m} = 1600 \text{ J}$$

The work output is the work done by the machine. So in the example in Figure 2.13, the machine has lifted the student in the wheelchair up 2 m. The downward force exerted by the student in the wheelchair is 800 N. You can use the formula for work again to calculate the work output.

$$W_{output} = F_{output} \times d_{output}$$

$$\text{Work}_{\text{output}} = 800 \text{ N} \times 2 \text{ m} = 1600 \text{ J}$$

In the example, both the work input and work output equal 1600 J. But the pushing student had to exert a force of only 320 N to move the student in the wheelchair to a height of 2 m. Without the ramp, it would have taken a force of 800 N to lift the student in the wheelchair to a height of 2 m.

Do you think the work input and the work output are always equal?

reSEARCH

Power

Power is the amount of work done in a set period of time. Find out how power is calculated and what units are used for it. In what applications is power measured?

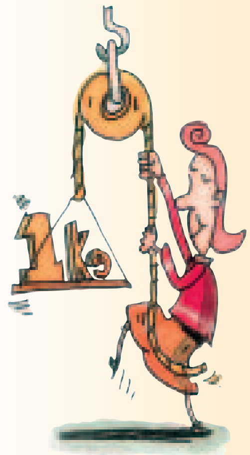
Give it a TRY ACTIVITY

WORK INPUT AND WORK OUTPUT

You can see for yourself if the work input and the work output of a machine are always equal. If you were to lift a 1-kg mass 1 m, you would be doing 9.8 J of work.

How much work would a pulley do lifting a 1-kg mass 1 m? Use a single pulley, a 1-kg mass, a spring scale, and a metre-stick to find out.

Calculate the work input and the work output for the pulley. Are they different? If so, why do you think they are different?



Work and Friction

In subsection 2.1, you learned that the mechanical advantage of a machine does not equal its speed ratio in real situations. The reason is friction. Friction is also the reason that work input does not equal work output in real situations. It affects a machine's efficiency. Earlier you learned one way of calculating efficiency. Efficiency can also be calculated using work input and work output. Here's an example of a device that is 75% efficient.

$$\text{Efficiency} = \frac{\text{Work}_{\text{output}}}{\text{Work}_{\text{input}}} \times 100 = \frac{1200\ \text{J}}{1600\ \text{J}} \times 100 = 0.75 \times 100 = 75\%$$

Check and Reflect

1. Is work being done in the following examples? Explain your answer in each case.
   a) A hiker puts her backpack on.
   b) A gardener pulls on a large weed as hard as he can, but he can't get it out of the ground.
   c) A student memorizes a poem.
2. You use a force of 40 N to push a box of books 3.2 m along the floor. How much work have you done?
3. Use an example to explain the effect of friction on a machine.
4. a) What is work input?
   b) What is work output?
   c) Are they ever equal? Why or why not?
5. At the beginning of this subsection, you developed your own definition of work. How close was your definition to the scientific definition? What changes did you make to your definition as you read through the subsection?
6. Calculate the work done in the following situations:
   a) A 15-N box is lifted 0.5 m.
   b) A 500-N table is pushed 200 cm up a ramp.
   c) A pulley is used to lift a 1000-N piano up 10 m.
7. A person uses a lever to lift a 5-N box 20 cm. Assume that the lever is 100% efficient.
   a) What is the work input done by the person?
   b) What is the work output done by the lever?
8. A person riding a scooter for 1000 m exerts a constant average force of 10 N. Under ideal conditions, what is the work output done by the scooter?
9. A person does 500 J of work to move a box of oranges 25 m. What force was required to move the box?

2.3 The Big Movers—Hydraulics

Figure 2.14 The fluid in the hydraulic system of this backhoe transmits forces that move the levers for lifting heavy loads.

Most machines that move very large objects use a hydraulic system that applies force to levers or gears. A **hydraulic system** uses a liquid under pressure to move loads. A hydraulic system increases the mechanical advantage of the levers in machines such as the backhoe shown in Figure 2.14.

Before hydraulic systems were invented, construction projects were done mainly by hand, using simple machines such as ramps, levers, and the wheel and axle. Large structures made thousands of years ago, such as the Egyptian pyramids, are truly amazing. Imagine moving and placing five-tonne blocks of stone using only ropes, wooden levers, and ramps!

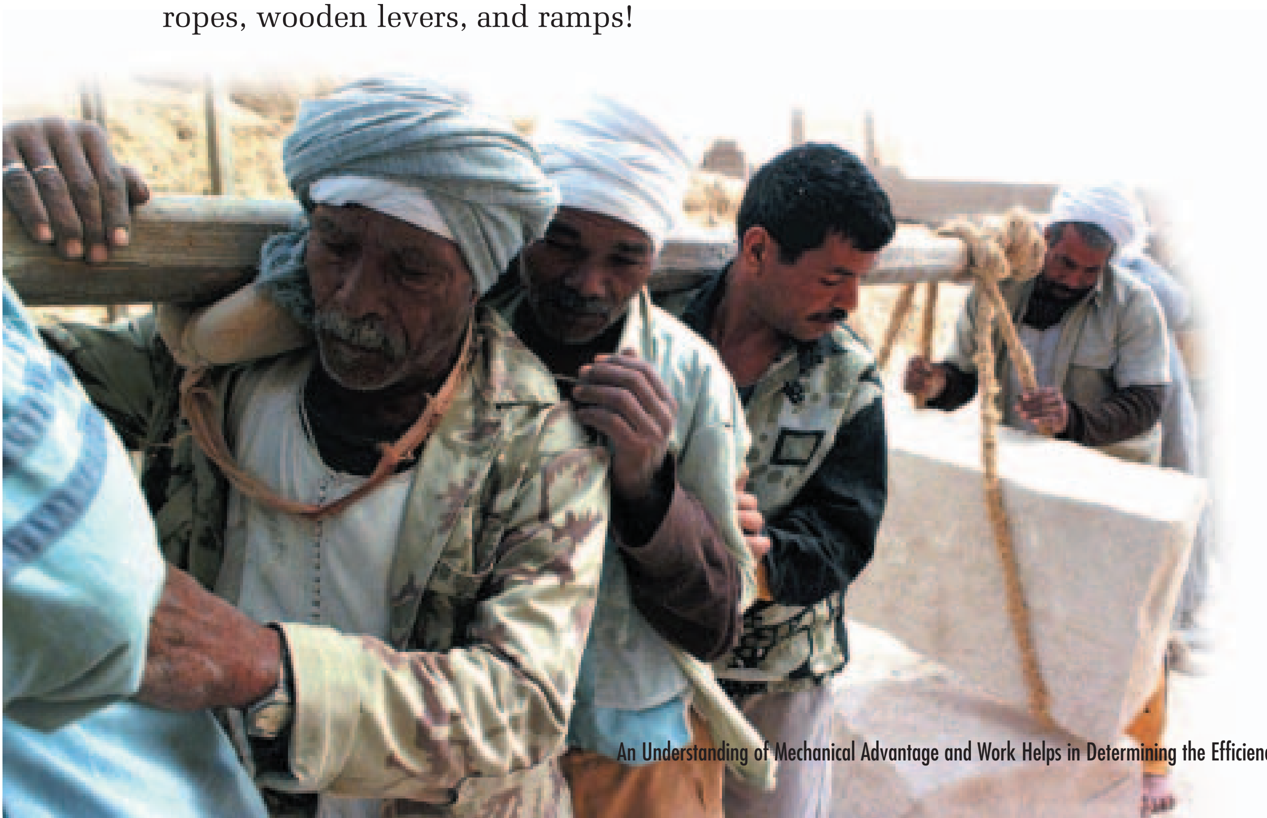


Figure 2.15 In the past, large structures were built with much hard physical work by many people over a long time. Hydraulic systems make it possible for one person to lift huge loads.

Modern construction projects are much safer and can be done much more quickly with the mechanical advantages of hydraulic equipment. Hydraulic systems are used in many places other than construction sites, however. Hydraulic devices perform tasks ranging from raising the height of a hair stylist's chair to controlling the brakes in a car.

Figure 2.16 The hydraulic system enables the hair stylist to raise or lower the chair easily.

Pressure in Fluids

Hydraulic systems work because they use fluids under pressure. From earlier studies, you may recall that **pressure** is a measure of the amount of force applied to a given area. It can be written as an equation: $p = F/A$, where p is pressure, F is force, and A is area. The unit of measurement for pressure is the pascal (Pa). This unit is named after Blaise Pascal, a scientist who did important research on pressure in fluids. One pascal equals the force of 1 newton over an area of 1 m^2. This is such a small amount of pressure that scientists usually use kilopascals when recording pressure measurements. Note that pressure can also be measured in newtons per square centimetre (N/cm^2).

In his research, Pascal discovered that pressure applied to an enclosed fluid is transmitted equally in all directions throughout the fluid. This effect is known as **Pascal's law**. This law makes hydraulic and pneumatic systems possible. These two types of systems both use fluids under pressure to move loads. Hydraulic systems use liquids, and pneumatic systems use gases (usually air). You can find out more about pneumatic systems in Unit A: Mix and Flow of Matter.

A common application of Pascal's law is the hydraulic jack. A jack is any device used to lift something. You may have seen a hydraulic jack used for lifting or moving objects in a store. Figure 2.17 shows how a simple hydraulic jack works.

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Air Pressure

You have probably heard of low or high pressure systems in weather. We don't think of air having weight. But it's the weight of the air above us that creates pressure. Average air pressure at sea level is about 100 kPa or 100 000 N of force for every square metre.

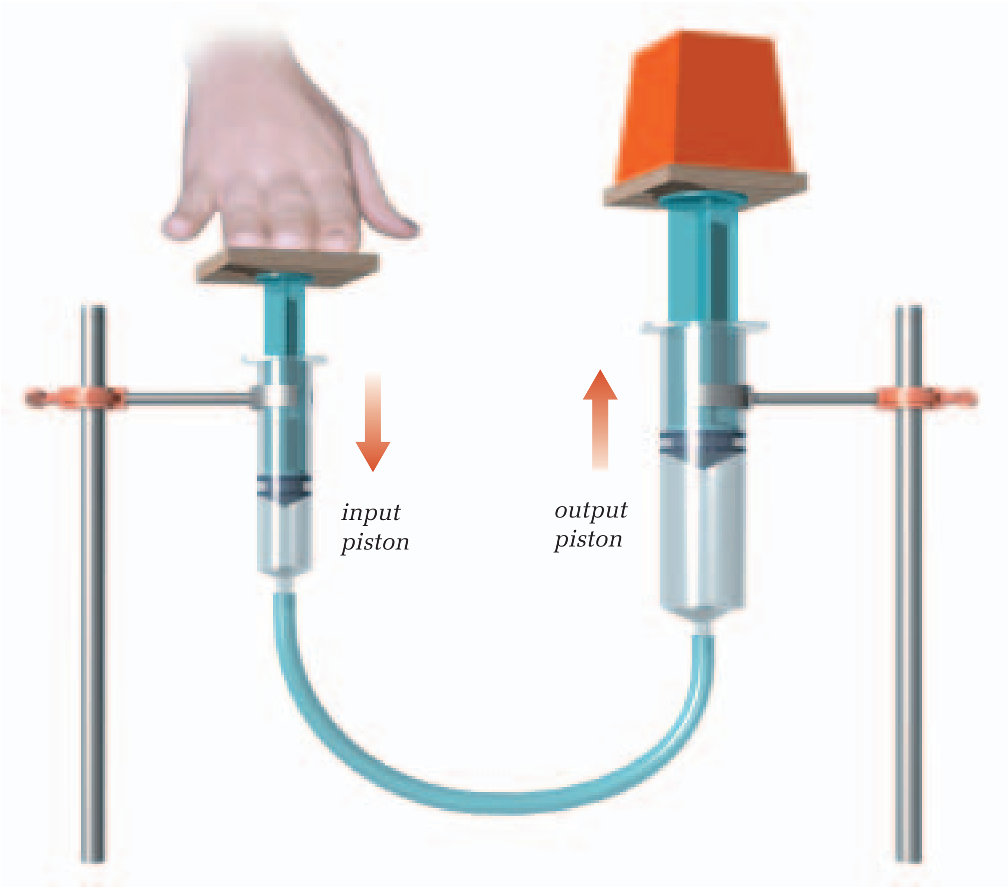


Figure 2.17 A simple hydraulic jack works because of Pascal's law.

A Piston Creates Pressure

In hydraulic systems, the pressure is created using a piston. A piston is a disk that fits tightly inside a cylinder. As the disk moves inside the cylinder, it either pushes fluid out or draws fluid into the cylinder. Pistons can be very small (e.g., 1 cm^2 in a small syringe). Or they can be very large (e.g., a few square metres in a hydraulic car hoist).

Hydraulic devices use a combination of two pistons attached to either end of a cylinder or flexible pipe. Figure 2.17 shows the parts of a hydraulic system. The first piston is the *input piston*. This piston is used to apply the force to the fluid, which creates pressure in the fluid. The fluid transfers this pressure to the *output piston.* The fluid transfers the pressure equally in all directions. So the pressure on the output piston is equal to the pressure created by the input piston.

This pressure exerts a force on the output piston, which causes the piston to move. The pressure in the fluid provides the mechanical advantage that makes hydraulic systems so useful. Let's look at how it does that.

math Link

The human heart is an excellent pump. It distributes blood throughout the body, creating pressure in the blood vessels. Normal maximum blood pressure for a healthy person is 16 000 Pa. The artery carrying the blood from the heart has an average diameter of 1.5 cm. Calculate the force supplied by the heart to produce normal blood pressure.

Inquiry Activity

MECHANICAL ADVANTAGE IN A HYDRAULIC JACK

Before You Start ...

A jack is any device used to lift objects. You will use syringes and flexible tubing to create a model of a hydraulic jack. The plungers in the syringes are pistons.

Materials & Equipment

- 2 50-mL syringes, each with a platform
- 10-mL syringe with platform
- small plastic tub
- water
- 30 cm of latex tubing
- 4 burette clamps
- 2 support stands
- 1-kg mass

The Question

How does pressure create mechanical advantage in a hydraulic jack?

The Hypothesis

Write a hypothesis that describes how the pressure in a hydraulic jack creates a mechanical advantage. Hint: Think about the relationship between force and piston area in a hydraulic system.

Procedure

1. Measure the diameter of the plungers in one of the 50-mL syringes and in the 10-mL syringe. Calculate the area of each plunger and enter it in your table.
2. Connect the two 50-mL syringes with the latex tubing. Remove the plungers from both syringes. As shown in Figure 2.18, hold the syringes at the same level. Have your partner pour water into one until both are full.
3. Remove all the air from both syringes and the tubing. Insert the plunger into one syringe and push it all the way down. Use the plastic tub to catch the overflow from the other syringe. Insert the plunger into the second syringe and push it halfway down. No air should be left in the syringes or the tubing.

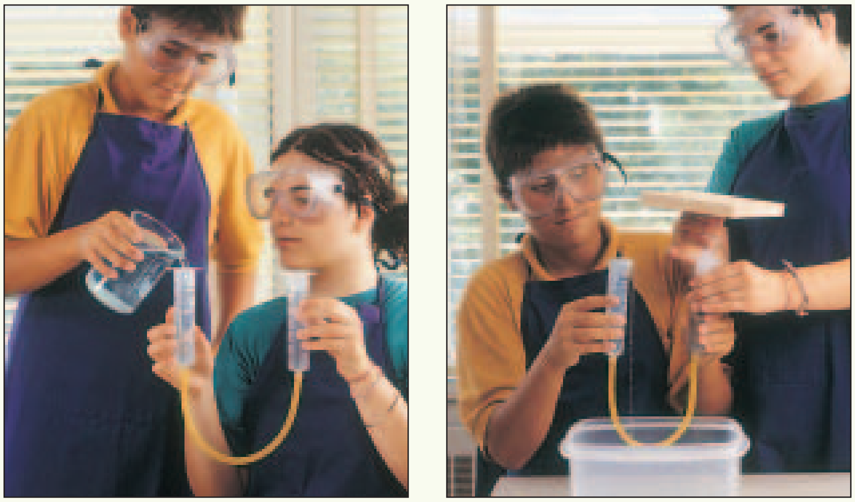


Figure 2.18 Steps 2 and 3. It is important to make sure that there is no air in the syringes before you begin.

4. Check that the plungers move easily in each syringe. If one or both of them stick, move first one plunger, then the other until they slide easily.
5. Using the burette clamps, mount each syringe on a support stand. Have your partner hold one support stand steady and place the 1-kg mass on that syringe's platform. Hold the other support stand steady as you push down on that syringe's platform until the mass on the other syringe moves.

6 Move the 1-kg mass over to the other platform. Hold both support stands steady as you push down on the empty platform until the mass moves. Be aware of how much force you needed to move the mass in this set-up. Record this amount of force as your "control force."

7 Remove the 1-kg mass and take both syringes off the support stands. Carefully remove the latex tubing from one of the 50-mL syringes, allowing the water to drain out of both syringes and the tubing into the plastic tub. Keep the latex tubing attached to the other 50-mL syringe.

8 Connect the 10-mL syringe to the 50-mL syringe with the latex tubing. Fill the syringes with water, as described in step 2. But this time, insert the plunger in the 50-mL syringe and push it down only halfway. Then insert the plunger in the 10-mL syringe. As before, check that the plungers move easily.

9 Repeat steps 4 and 5. Be aware of how much force you needed to move the mass each time in this set-up. Enter this information as "more than control force" or "less than control force" in your table.

Collecting Data

10 Record your observations in a table like the one shown below.

Area of the plunger		Force needed
Plunger pushed on	**Plunger supporting 1-kg mass**	
plunger in 50-mL syringe	plunger in 50-mL syringe	control
plunger in 50-mL syringe	plunger in 10-mL syringe	
plunger in 10-mL syringe	plunger in 50-mL syringe	

Analyzing and Interpreting

11 Why was the word "control" used to identify the force you used to push down the mass when both syringes were the same size?

12 Which situation allowed you to use the least amount of force to raise the 1-kg mass?

13 a) A 1-kg mass exerts a force of 10 N. Use the formula $p = F/A$ to calculate the pressure exerted on the water by each plunger when the 1-kg mass was sitting on it.

b) Which plunger exerted more pressure on the water?

c) Which plunger exerted more pressure on the opposite plunger? Explain your answer.

Forming Conclusions

14 Use your observations and diagrams to prepare a brief summary report explaining how pressure creates mechanical advantage in a hydraulic system. Hint: Recall that mechanical advantage is a ratio of output force to input force.

MECHANICAL ADVANTAGE IN HYDRAULIC SYSTEMS

The mechanical advantage in a hydraulic system comes from the fluid pressure in the system. Figure 2.19 shows another example of a simple hydraulic jack. The force applied to the input piston creates pressure in the fluid. This pressure is transferred throughout the fluid and presses on the output piston. This creates a force on the output piston. So when you push on the smaller input piston, it presses on the fluid, which presses up on the larger output piston, which lifts the object.

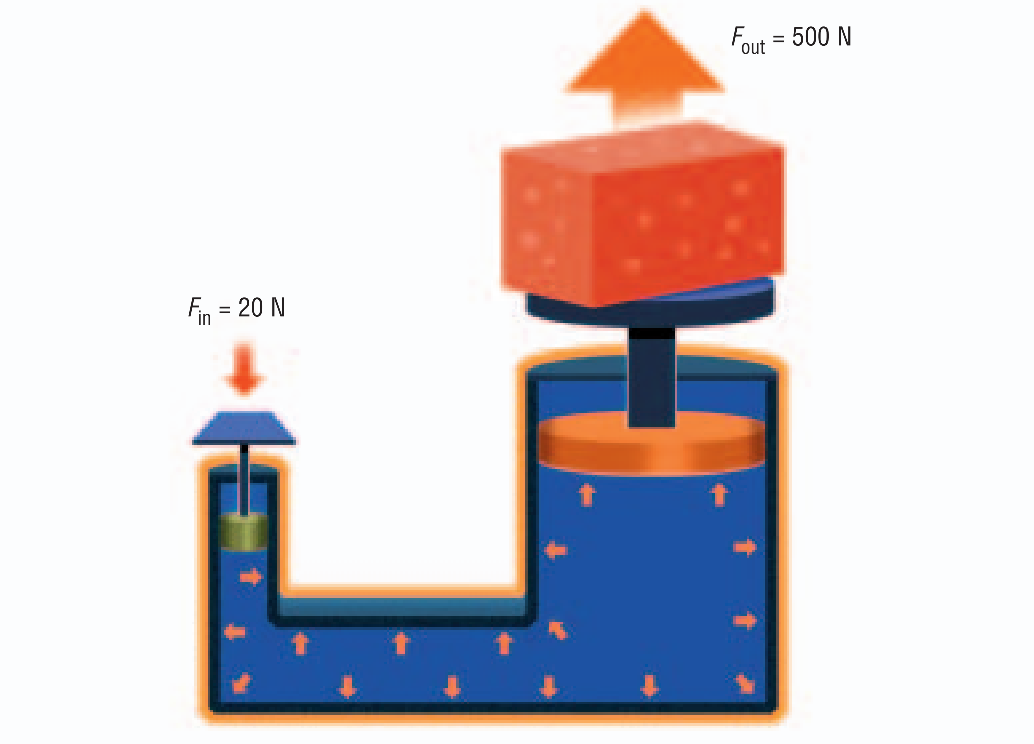


Figure 2.19 This hydraulic jack has a mechanical advantage of 25.

You can calculate the mechanical advantage of a hydraulic jack if you know the input and output forces. In the example shown in Figure 2.19, the input force is 20 N and the output force is 500 N. Recall that the formula for calculating mechanical advantage is MA = Output force ÷ Input force. So for this jack:

MA = 500 N ÷ 20 N = 25

The jack's mechanical advantage is 25.

Earlier in this unit, you calculated the mechanical advantage for pulleys and other mechanical devices. Recall that these mechanical advantages were numbers like 4, 8, or 12. So 25 is a large mechanical advantage.

PRESSURE AND MECHANICAL ADVANTAGE

The reason for the large mechanical advantage in a hydraulic system is the ability of the fluid to transmit pressure equally. It allows you to use a smaller force on the small piston to produce a larger force on the large piston.

Recall that $p = F/A$. Assume the small piston has an area of 4 cm^2 and the force it applies to the fluid is 20 N.

$$p = F/A = 20\ N/4\ cm^2 = 5\ N/cm^2$$

So the small piston creates a pressure of 5 N/cm^2 in the hydraulic fluid.

From Pascal's law, we know that the pressure the small piston creates is the same everywhere in the fluid. So this is pressure at the large piston. The large piston has an area of 100 cm^2. What force is exerted on the large piston? This force will push the piston up, which will raise the 500-N load in our example.

Think of the force and area at each piston as ratios that have to be equal. They both have to equal the pressure of 5 N/cm^2 in our example. So the force of the small piston divided by the area of the small piston must equal the force of the large piston divided by the area of the small piston. Here's how that looks:

$$\frac{\text{Force of the small piston}}{\text{Area of the small piston}} = \frac{\text{Force of the large piston}}{\text{Area of the large piston}} = 5\ N/cm^2$$

Our ratios are: $\frac{F_{small}}{A_{small}} = \frac{F_{large}}{A_{large}}$

$$\frac{20\ N}{4\ cm^2} = \frac{X}{100\ cm^2}$$

We solve the equation and find that X equals 500 N. So the force exerted on the large piston by the fluid is 500 N—much larger than the 20-N force that the small piston exerted on the fluid in the first place.

This example shows the difference in forces created within a hydraulic system. This difference provides the mechanical advantage in a hydraulic system. Their large mechanical advantages make hydraulic systems useful in many applications—from amusement park rides to pipelines.

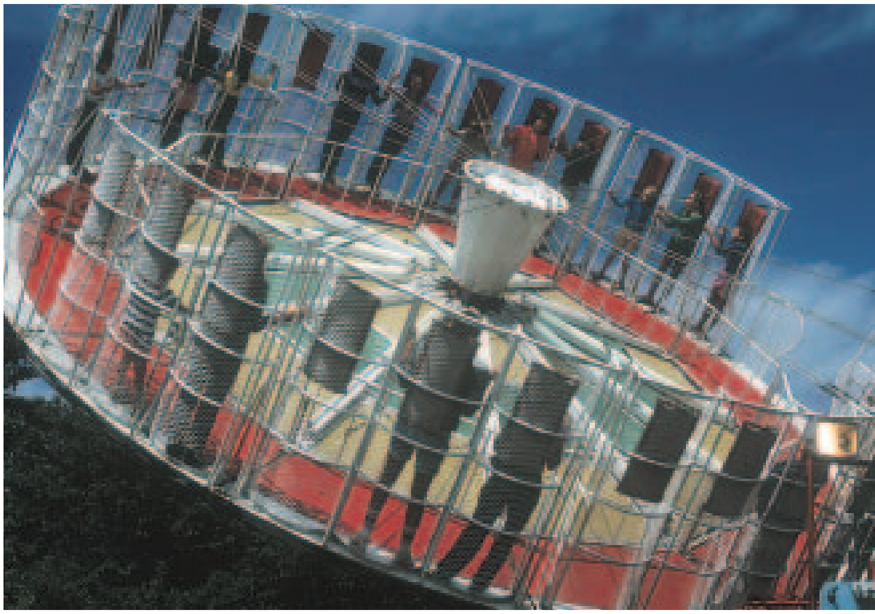


Figure 2.20 This ride uses a hydraulic system to create thrills. Hydraulics in the base of the ride lift and slant the platform as it spins.

Larger Force—Greater Distance to Move

You may recall from earlier in this unit that the mechanical advantage of simple machines came at a cost. For example, the mechanical advantage of a lever produced a larger output force. The shortcoming of the lever is that the input force has to move a greater distance than the output force. The mechanical advantage of hydraulic systems has a similar shortcoming. To increase the force on the output piston, the input piston has to move a greater distance.

reSEARCH

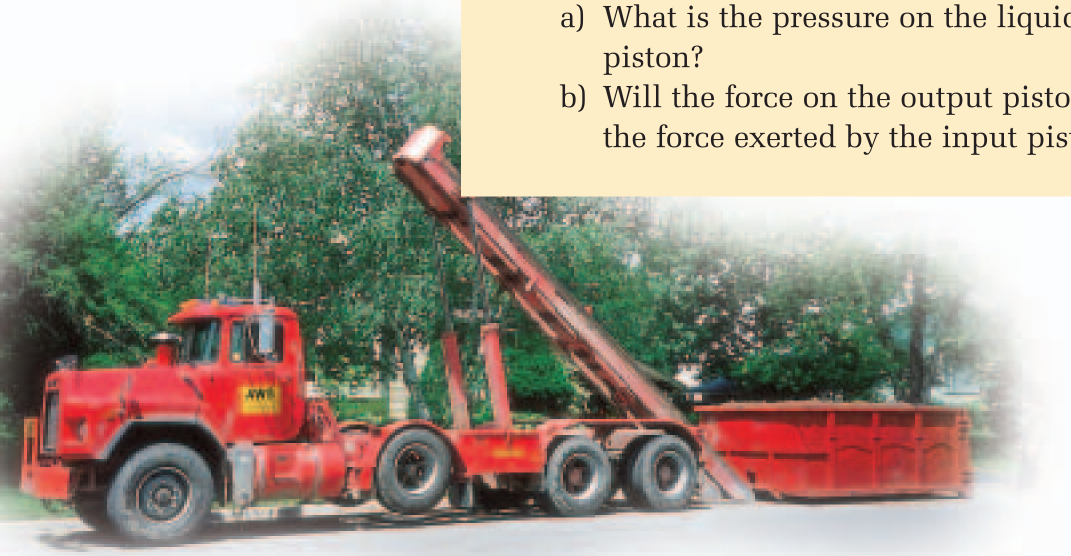
Hydraulic and Pneumatic Devices

Use the Internet or your library to determine whether each device below is hydraulic or pneumatic. Where possible, try to determine the mechanical advantage of each device.

- bicycle pump
- front-end loader
- flap controls on an airplane
- air conditioner

Check and Reflect

1. What is a pascal? What does it measure?
2. How do the sizes of the pistons affect the pressure in a hydraulic system?
3. Describe how forces are transferred in a fluid.
4. A hydraulic lift has 2000 N applied to an input piston that has an area of 50 cm^2. The output piston has an area of 200 cm^2.
   a) What is the pressure on the liquid exerted by the input piston?
   b) Will the force on the output piston be the same or less than the force exerted by the input piston? Explain your answer.



Experiment
ON YOUR OWN

BUILD A WATER-DRIVEN DEVICE

Before You Start ...

One of the earliest methods of providing energy to a mill or factory was to use the force of falling water. Water was channelled to pass over the top of a large wheel. The water would catch on paddles or buckets on the wheel, which forced the wheel to turn. The axle for the wheel extended into the mill. Belts attached to this axle would transfer the wheel's force to turn saws or grind flour.

In this activity, your challenge is to build a device that can use energy from flowing water to lift the largest mass possible a vertical distance of 10 cm.

The Question

How can you construct a mechanical device driven by water that can lift a mass a vertical distance of 10 cm?

Design and Conduct Your Experiment

1 Your teacher will show you the lift mechanism that you will use for this activity. Notice that your device must connect to this spool or tube, which has a string attached to it. The other end of the string will be attached to the mass. The device must turn the spool or tube so the string winds around it enough to lift the mass 10 cm.

2 Working in a small group, determine what combinations of simple machines would be useful in building this device. You may find it helpful to review the information on simple machines on pages 261 to 265 and page 268 earlier in this unit.

3 Create a plan of how you will build your device. Include a diagram showing how you plan to connect the simple machines together. Also include a list of materials that you will need to create your device. **Note:** Your source of water will be a thin hose connected to a tap. The tap will only be turned on low—it will provide a source of gently flowing water, not water under pressure.

Figure 2.21 Flowing water causes this huge wheel to move. Linkages connect the moving wheel to mechanical systems that operate the mill.

4 Build your device and test it. Remember: changes and modifications are part of the development process.

5 What was the largest mass your device could lift?

6 Be prepared to demonstrate your device to the class. Compare your device with others. How successful were the other devices?

7 After observing the other devices, describe one modification you would make to your device to improve how it functions.

8 How could you estimate the mechanical advantage of your device?

Careers and Profiles

PRACTICAL DESIGNERS

Mechanical engineers design engines and machines that extend our physical capabilities. These machines include automobiles, aircraft, ships, trains, spacecraft, robots, earth-moving equipment, harvesting machines, nuclear power plants—basically any object or device that moves. Colette E. Taylor is a mechanical engineer. Since 1988, she has worked at Chalk River Laboratories in Chalk River, Ontario. Here, she does research, along with other scientists and engineers, that supports and advances the development of CANDU nuclear reactor technology.

Q: Why did you choose to become a mechanical engineer?

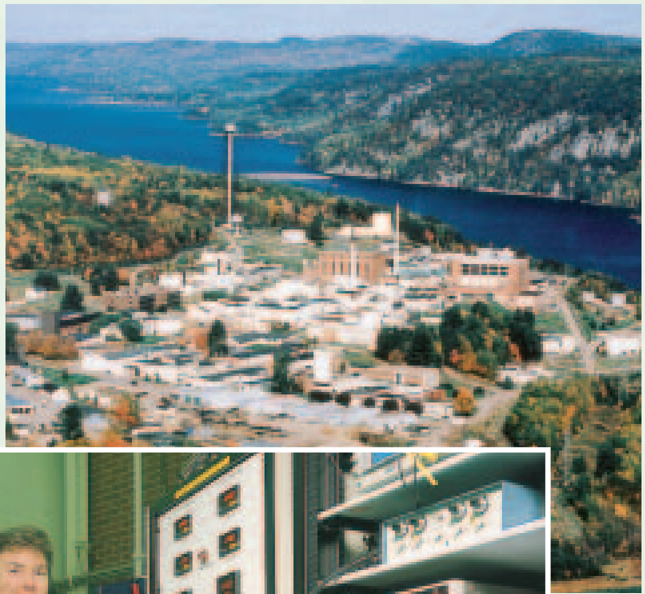
A: When I was in high school, I had no idea what a mechanical engineer was, but I really enjoyed taking a wide range of science courses. I didn't want to specialize in any one thing. I wanted to use all of my science background. When I looked at the options for university, I discovered that mechanical engineering was one of the few career choices that required you to use a wide range of sciences. It was perfect!

Q: Are there many women mechanical engineers?

A: There were nine women in my graduating class of 135 students. And that was considered high! I think women have a distorted idea about what engineers really do. They think that you have to work with big, dirty, noisy equipment. Well, that's just not part of the job. I spend most of my day in meetings and working on new designs in my office.

Q: What does it take to be a good mechanical engineer?

A: Strong technical ability, communication skills, and high motivation are important characteristics for a successful engineer in today's competitive and demanding workplace.



Colette Taylor conducts research at the CANDU nuclear generating station in Chalk River, Ontario.

Colette says, "If you want a job that challenges you each and every day, and provides you with a wide variety of career opportunities, mechanical engineering is an excellent choice."

1. Why do you think a career in mechanical engineering would give you "a job that challenges you each and every day"?
2. If you were a mechanical engineer, what kind of machines or systems would you like to work on?

Assess Your Learning

1. Describe how to calculate the following aspects of a mechanical system:
   a) mechanical advantage
   b) efficiency
   c) speed ratio
2. Is it possible for a machine to be 100% efficient? Explain your answer.
3. Calculate the work done by a student doing 10 chin-ups. Assume that the student exerts a force of 400 N with arms that are 0.5 m long.
4. Describe how you could measure the efficiency of a bicycle.
5. A pulley system allows a load of 625 N to be lifted by a 90-N input force. What is the mechanical advantage of the pulley system?
6. Imagine that you work in a company that builds robots. You are asked to design a robot with hydraulic arms that can help out in the home.
   a) List some of the activities that this robot could use its hydraulic arms for.
   b) Why would hydraulic arms be better for these activities than mechanical arms without hydraulics?

Focus On SCIENCE AND TECHNOLOGY

Scientists and engineers always encounter new questions and problems in scientific research and technology development. Think about the information you learned and the activities you did in this section.

1. Describe one problem you encountered in this section and how you solved it.
2. Do you think there could be more than one way to solve the problem you described in question 1? Why or why not?
3. After learning about mechanical advantage, what two new questions do you have about it?

3.0

Science, society, and the environment are all important in the development of mechanical devices and other technology.

Key Concepts

In this section, you will learn about the following key concepts:

- design and function
- social and environmental impacts

Learning Outcomes

When you have completed this section, you will be able to:

- evaluate the design and function of a mechanical device in relation to efficiency and effectiveness
- identify the impacts of a mechanical device on humans and the environment
- develop and apply criteria for evaluating a mechanical device
- describe how the following factors affect technological development: advances in science, trial and error, and changes in society and the environment

Mechanical devices have evolved over time because of new developments in science and technology. The first lawn mowers, for example, were made of steel. They were powered by the person pushing the mower. Since then the lawn mower has been adapted to use first gasoline and later electricity as a source of energy. Most of the steel parts have been replaced by aluminum or plastic. The change in materials makes the mower lighter and easier to use. It also reduces its cost. Each change to the lawn mower was designed to make the machine more efficient, less expensive, and easier to use.

In this section, you will explore how the design and function of a mechanical device are related to its efficiency and effectiveness. You will also consider the effects that a device can have on the environment. Finally, you will look at how science and technology advance—through knowledge, trial and error, and changes in society and the environment.

For Web links relating to 3.0, visit **www.pearsoned.ca/scienceinaction**

3.1 Evaluating Mechanical Devices

Mechanical devices are constantly being evaluated. Manufacturers evaluate the devices they make to find ways to improve them. They want more people to buy their products so they want the devices to be better than, or different from, other brands. Inventors evaluate mechanical devices to find ways to make them easier to use or to find other ways of doing the same task. And you evaluate mechanical devices every time you use one or consider buying one.

Using Criteria to Evaluate a Device

Your bicycle has broken down. You need to buy a new one, but there are many bike designs available. How do you decide which one to buy?

Working with a partner, list the features that you would like to have in a bicycle. Begin by thinking about what you use your bike for. Is it for riding on city streets? Is it for riding on trails out in the country? Is it for BMX riding? Will you ride it to school? If so, you need some method of carrying things. Will you be riding after dark? If so, you need to make sure you have good lights and plenty of reflectors.

The list of features you want are your criteria for evaluating a bike's design. That is, they are the features you will consider when you look at different bike designs to see if they meet your needs. Look at the bicycles shown in Figure 3.1. Do any of them fit your criteria?

Of course, the features in the list you made are not the only criteria you have to consider when you buy a mechanical device. A very important one is cost. You may find a bike that fits all your criteria exactly, but if it's out of your price range, you can't buy it. When you evaluate a mechanical device or anything else, it's important to be clear about all the criteria that you have to consider.

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Bikes without Brakes

Would you buy a bike without brakes? You would if you wanted it for track racing in a velodrome. You may have seen these bikes on television at the Olympics. They have no brakes and only one gear. The gear is sized according to the type of competition and the cyclist using the bike.

Figure 3.1 Do any of these bicycle designs meet your criteria?

Efficiency and Effectiveness

When you use a mechanical device, you want it to work efficiently. Earlier in this unit, you learned that efficiency could be calculated as a percentage by dividing the mechanical advantage by the speed ratio. That's quantitative measure of efficiency because it gives you a number for a quantity or measurement. But efficiency can also be described qualitatively, just in words. For example, you can describe the efficiency of a mechanical device by saying how quickly and easily it helps you do a task. You also want a mechanical device to work effectively. It works effectively if it does its job well.

You can see the difference between efficiency and effectiveness by comparing different designs of bicycles. For example, a one-speed bicycle is effective in carrying you from one place to another. And it's more efficient than walking—you get there faster and use less energy to cover the same distance. A 21-speed bicycle is just as effective as a one-speed, but it's more efficient. By changing gears, you can increase your speed and climb hills more easily. You can cover the same distance more quickly and use less energy. That makes the 21-speed bike more efficient. So both designs are effective, but one is more efficient than the other. Usually, in evaluating a mechanical device, you are looking for the best combination of effectiveness and efficiency at a cost that you can afford.

Figure 3.2 The people in this photo use their bicycles as their main means of transportation for going to work, for visiting, and for shopping. Many of these are one-speed bicycles.

Function and Design

Scientists, engineers, and other inventors want to develop mechanical devices that work efficiently and effectively. To do that, they consider both the function and design of the device. The **function** is what the device is supposed to do. The **design** is the physical form of the device that makes it usable.

Figure 3.3 How do the designs of the mountain bike and the road racing bike show the different functions of the two kinds of bikes?

Think again about the bicycle. The basic function of a bicycle is to carry a person. But different types of bicycles have very specific functions, and their designs reflect these functions. Look at Figure 3.3. The two bicycles shown are both used for racing. However, the type of racing they do is so different that the designs are very different. They both have two wheels, handlebars, brakes, and seats, but even these look different. An important aspect of evaluating mechanical devices is ensuring that the design suits the function.

Evaluation for Development

If you are buying a mechanical device, you need to think about how to evaluate it. A thorough evaluation helps you make a better choice that suits your needs. Another reason for evaluating a device is to determine how it can be improved.

Earlier in this unit, you saw photos of how bicycles have changed from the early penny farthing to today's high-tech bikes. The design of bicycles is constantly being changed to improve how they function and to make them more comfortable and easier to use. The efficiency and effectiveness of bicycles as a means of transportation has greatly increased over the years.

Another factor that can be considered in evaluating mechanical devices is the environment. Sometimes the environment influences the design and function of a device. For example, mountain bikes are designed specifically for rough terrain. They have sturdier frames and larger tires than road-racing bikes do. Both these features help mountain bikes function more efficiently and effectively.

Considering the Environment

The effect of a device on the environment should also be considered in evaluating it. For example, spikes in the tires on a mountain bike might make the bike more effective in climbing slopes. However, tires with spikes would tear up the soil and plants even more than ordinary bike tires do. To protect the local environment, tires with spikes should not be used. Other devices, such as cars, affect the environment by contributing to air pollution. This can affect you directly and can contribute to global warming.

Figure 3.4 Leaf blowers help people clean leaves off roadways and paths. Some people feel that these devices pollute the environment with their noise. What criteria would you use in trying to decide whether to buy a leaf blower?

Evaluating a Mechanical Device—A Case Study

A good example of how evaluation leads to the development of better mechanical devices is a product that you use almost every day—the pop can opener. Its changes over the years show how evaluating a mechanical device can lead to improvements. These improvements made the product more convenient. They also affected the well-being of both people and the environment. The history of the pop can opener shows how trial and error can play a role in the development of even simple technology.

The development of an opening mechanism for the aluminum can went through four distinct designs:

- the church key
- the removable pull tab
- the buttons
- the non-removable tab

Each new design was the result of the previous device having some problem. Before you start reading about pop can openers, make a chart like the one below in your notebook. As you read, fill in the advantages and disadvantages of each design.

Opener Design	Advantages	Disadvantages
church key		

Evolution of a Mechanical Device—The Pop Can Opener

To pour a liquid out of any container, you need two holes or one large hole. With two holes, the first hole allows the air into the can. The second hole lets the liquid out. The air flowing into the can replaces the liquid that is leaving the can. In fact, the air helps to create a smooth flow of liquid out of the second hole. One hole will work if it is large enough to let air flow into the can at the same time that liquid flows out of it. So one of the criteria for the design of an opener was that it could make either two small holes or one large one. Let's look at how pop can openers evolved.

Figure 3.5 The earliest cans were made of iron. They could be opened only by using a hammer and chisel!

Church Key

Figure 3.6 The church key was the first practical design for a can opener.

The first cans were completely sealed. They did not have an opener built into the lid. An opening device was needed to make two holes in the top of the can. This device was called a church key. A common church key is a piece of metal with a triangle end designed to punch into the can and open it. Figure 3.6 shows a church key being used to make two holes in the top of a can.

A church key is a simple machine—a lever. If you pressed on the top of the pop can with just your fingers, you would not have enough force to open it. The church key multiplies the force that you use. It also focusses it to a tiny point at the end of the triangle. Recall that pressure is the amount of force applied to a given area. So by using the church key lever to press on a tiny point on the top's surface, you can puncture the metal. The church key worked well, but it did have some drawbacks. Can you think of at least one problem with using a church key? Add the advantages and the disadvantages of the church key to your chart.

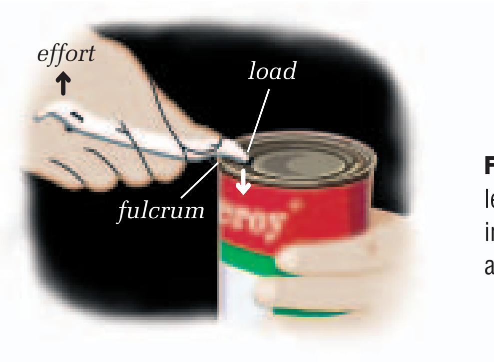

Figure 3.7 The church key is a lever that enables you to increase the pressure you can apply to the top of a can.

Removable Tab Top

Figure 3.8 The removable tab top made opening the cans much easier. It was a simple machine built right into the top of the can. But it too had problems.

One sunny summer day in the early 1960s, Ermal Fraze of Ohio was picnicking at the local lake. Unfortunately he forgot the church key to open his cans of soda pop. It was clear that this was a failure of the church-key can. If you didn't have a church key with you, you couldn't open the can. Fraze was determined to find a better solution. Making sketches, the metal engineer designed his solution on paper.

Fraze solved the problem by having a ringed tab that could be pulled off the top of the can. After much trial and error, he found the right design. When you wanted a drink, you would put a finger in the ring part of the mechanism and pull back the ring like a lever. The tab would "fail" and rip from the lid. Now you could have your drink. Not needing a church key was a big improvement, but an environmental problem arose from the new pull tab design. What do you think that was?

Buttons

With billions of cans being used every year, an environmental problem arose with the removable pull tab. What do you do with the tab after you take it off the can? Many people just threw their tabs onto the ground. The result was a litter problem and a safety hazard. A new solution was needed.

One solution was to have two holes with buttons pre-formed in the can's lid. One hole was smaller than the other. The directions on the can told the user to open the small hole first.

Recall from earlier lessons that pressure is force divided by area. By pushing on the small button, you exerted the same force as you would on the large one, but over a smaller area. You created more pressure at that point, so the smaller button was easier to open.

Opening the small button released the pressure in the can. This pressure came from the can's contents, usually carbonated pop. The bubbles in pop are carbon dioxide. In order to keep the bubbles in the pop, the can has to be sealed to contain this pressure. Once this pressure was released by opening the small hole, the large button was much easier to open.

While this solution solved the litter problem, many people didn't like having to push two buttons. Some found the small button difficult to press. A better solution was once again needed.

Figure 3.9 The buttons eliminated the litter problem, but consumers didn't like using them.

Non-Removable Tab Top

In 1976, the easy-to-open top with an attached tab was invented. It eliminated the environmental problems of the earlier pull tabs, so it is called the "ecology top."

The tab top opener is another example of a simple machine. Like the church key, the tab top is a lever. This mechanical device and its specially designed metal top provide an easy-to-open product. Figure 3.10 shows how the tab top exerts pressure on the top of the can to open it. However, the lever action alone of the tab would not be enough to open a hole in the can. The metal has weaker lines in it that outline the shape of the hole. When you exert pressure using the tab lever, you strain the metal along the weaker lines, and the hole pops open.

Both the removable tab top and the non-removable tab top are mechanical devices that act as levers. The only difference is that the non-removable tab top stays attached and so does not create a litter problem.

Figure 3.10 Like the church key, the tab top is a mechanical device that is a lever.

Criteria for Evaluation

The changes to the pop can openers didn't happen accidentally. Can manufacturers evaluated each device and tried to improve it. To evaluate their can openers they probably asked questions such as:

- Is it efficient: does it open the can quickly and easily?
- Is it effective: does it allow air in so the liquid can flow out?
- Is it safe: does it create an opening that allows people to drink directly out of the can?
- Is it convenient: is it there when you need it?

These are just some of the questions they might have asked. After the problems with the removable pull tabs, they added questions about the environment. These included:

- Will the opener contribute to litter?
- Is the opener recyclable, along with the can?

As you were reading about pop can openers, you filled out a chart about their advantages and disadvantages. This is the type of information that is used in evaluating mechanical devices. However, in a real evaluation, you would begin with a list of things you want or are looking for in the device. The questions above are examples of how to start. This helps to ensure that you collect enough of the right kind of information to help you make your decision.

When you are buying, planning to use, or building a mechanical device, think of criteria that can help you evaluate your choices. These include: efficiency, effectiveness, design, function, and impacts on the environment and other people.

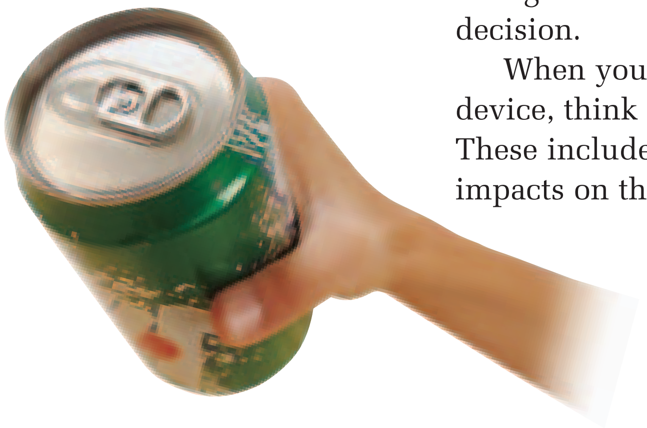

Figure 3.11 Today's aluminum cans are easy to open. Because the pull tabs stay attached to the cans, they don't contribute to litter.

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Making Sure That Consumer Products Are Safe

Next time you use a mechanical device like a hair dryer or toaster, look on the outside casing for a symbol that looks like a large C with a smaller S and A inside it. This symbol stands for the Canadian Standards Association (CSA). The CSA is a non-government association that tests and approves a wide range of products to make sure they are safe for consumer use. Other consumer product-testing organizations test for safety and value. Using the Internet or your library, find out how these organizations evaluate consumer products. Find out how they set the criteria they will use, and what kind of tests they do.

Decision Making Activity

Evaluating a Mechanical Device

The Issue

Every day you use a large variety of mechanical devices. Some are more efficient and effective than others. Some are better designed than others. You might notice how easy a device is to use, or how well it works in getting the job done. But do you notice whether it affects the environment? Or how it affects other people when you use it? What criteria should you use to evaluate a given mechanical device in a responsible way?

Background Information

1 When we think about buying a mechanical device, we usually have criteria to help us make a decision. Criteria are guidelines or standards that we use to gather information that we need for decision making. Usually these include only criteria directly related to our own use. But we should consider a wider range of criteria. That way, we can make sure that we buy and use mechanical devices and other technology more responsibly.

2 In any type of evaluation, you need to develop criteria. Depending on the situation, they may cover many aspects of a device, or only a few. Cost, energy efficiency, environmental impact, appearance, ease of use, comfort—these are just some of the criteria you might consider when you evaluate a mechanical device.

3 Imagine that the snowmobile was a new device about to be introduced onto the market. You are a member of an organization that tests consumer products. Your organization will be evaluating this new product to see if you should recommend its use. You are concerned not only about how the device meets the needs of individual consumers. You are also concerned about social and environmental factors.

a) Working with your group, develop a set of criteria that will help you evaluate the snowmobile. Remember to keep in mind the reason for your evaluation.

b) Evaluate the snowmobile. You will have to do some research to determine how well it fits your criteria.

Figure 3.12 What criteria would you use to evaluate this mechanical device?

Support Your Opinion

4 When your evaluation is complete, design a presentation to summarize your group's findings so you can share them with the rest of the class.

5 Be prepared to defend how well your evaluation criteria address social and environmental needs.

Check and Reflect

1. What personal and societal factors influenced the changes in devices used to open aluminum cans?
2. Do you think the design of the non-removable pull tab will change again or is this the final design? Explain your answer.
3. Your school wants to install a new bell. Which of the following are appropriate criteria for evaluating the bells available? Explain your answers.
   a) How well does the device do its job?
   b) How efficient is the device?
   c) Is the device waterproof?
   d) Are there any negative side effects to using the device?
   e) How reliable is the device?
   f) Is the device disposable?
   g) Does the device come in a wide variety of colours?
4. What other criteria would you add to help your school choose a suitable bell? (Hint: Think about what the bell will be used for, and its possible effect on people who live near the school.)

TRY This at Home ACTIVITY

Choosing a New Set of Wheels

You may have seen push scooters like this one—you may even have one of your own. Why do you think someone would choose to use one of these devices instead of a skateboard or roller blades?

- List the criteria someone might use to help her decide which device to buy.
- If you had to choose a new skateboard, a pair of roller blades, or a scooter, which one would you choose? Why? If you already have a scooter, explain your reasons for buying one.
- Why do you think these scooters are available now and weren't available 10 years ago? List as many factors as you can think of. Do some research by visiting stores that sell these devices and by searching the Internet to find out what these devices are made of. Which items on your list do you think are good reasons for the scooters' availability?
- Interview some of your friends to find out how they would make a choice among skateboards, roller blades, and scooters. Do any of them have a set of criteria that they use to evaluate purchases?

Figure 3.13 A push scooter

3.2 Technology Develops through Change

In subsection 3.1, you saw how a simple mechanical device like a pop can opener can develop over time. The changes in the pop can opener resulted from both human and environmental needs. New materials and technology also contributed to its development. The original steel cans changed to more flexible and lighter-weight aluminum. As well, new methods of making the cans helped.

Another part of the development process for pop can openers was failure—not all changes succeeded. The button-top pop can did not succeed because people found it difficult to use. Trial and error are also part of technology development.

Look at Figure 3.14, which shows how the sewing machine has developed for home use since it was invented in the 1800s. What factors do you think contributed to the changes in sewing machines over the years? (Think about the factors that affected the development of the pop can opener.)

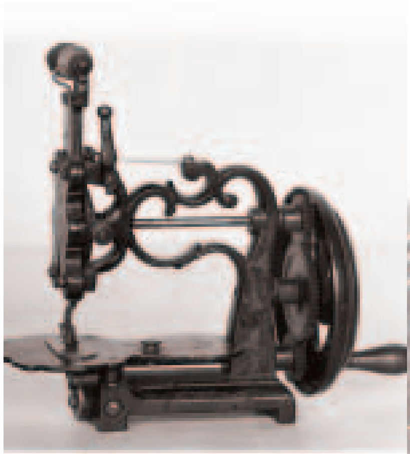

Figure 3.14a) Early sewing machines were operated by a hand crank. They could sew only simple stitches.

Figure 3.14b) A major development in sewing machine design was the development of the foot-operated treadle. This left the operator's hands free to guide the fabric better.

Figure 3.14c) Today's sewing machines run on electricity, and can produce a wide range of stitches.

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New Technology through Invention

In the winter of 1903, Mary Anderson was riding a streetcar in New York City. She noticed that the shivering driver had to keep getting out to wipe the snow and ice off the windshield. Mary had an idea, and made a quick sketch. Her device allowed the driver to operate a lever from the inside that moved a swinging arm on the outside that mechanically swept ice and snow off the windshield. By 1913, the windshield wiper was standard equipment on cars, trucks, and buses.

Advances in Science Result in New Technology

Many of the devices we use today—from computers to hair dryers—are possible only because of electricity. Charles Coulomb first identified electric charges in the 1700s. However, it wasn't until the late 1800s that electricity was distributed widely in cities. And it wasn't until the 1940s that it became widely available outside Canadian cities and towns.

As scientists, engineers, and other inventors learned more about electricity, they saw how it could be used in new technologies, such as light bulbs. They also found that electricity helped them make new scientific discoveries. For example, we would not have electron microscopes without electricity. These microscopes opened up a whole world that had been invisible to human eyes.

From Particles to Trains

Sometimes new technology develops from scientific research that may not even seem to be related. One example is the MAGLEV trains in Japan, shown in Figure 3.15. These trains are powered by electricity and float on magnets so that they never touch the tracks. They can travel at speeds over 350 km/h! The technology for the MAGLEV train resulted from physics experiments using particle accelerators.

Figure 3.15 Because they float on magnets, MAGLEV trains experience very little friction. This enables them to use more of their energy for increasing speed rather than opposing friction.

Particle accelerators are huge machines that break up atoms and other particles. To do this, they use large amounts of energy to create powerful magnetic and electric fields. Only a few particle accelerators exist in the world. It might seem that the specialized field of particle physics has very little to do with transportation. But scientists working in this field developed the technology that makes the MAGLEV train possible.

Changes in Society Result in New Technology

New technology can also result from changes to human society. An interesting example is the use of robots. Robots are widely used today, mainly in industry. But they don't look anything like the robots that were first popularized in movies and comic books in the mid-20th century. Those robots all looked like humans—with a head, torso, arms, and legs. The word "robot" comes from the Czech word *robotnik*, meaning "workers" or "slaves." It was first used in 1920 in a play in Czechoslovakia. In the play, human-like creatures were manufactured by the millions to work as slaves in factories.

While movie makers were busy creating fictional robots, scientists and engineers were trying to build real ones. The first practical examples were developed in the 1960s. Today, robots perform tasks far more efficiently and quickly than humans are able to do. Robots weld car bodies together, diffuse bombs, perform surgery, help the handicapped, and even explore other planets.

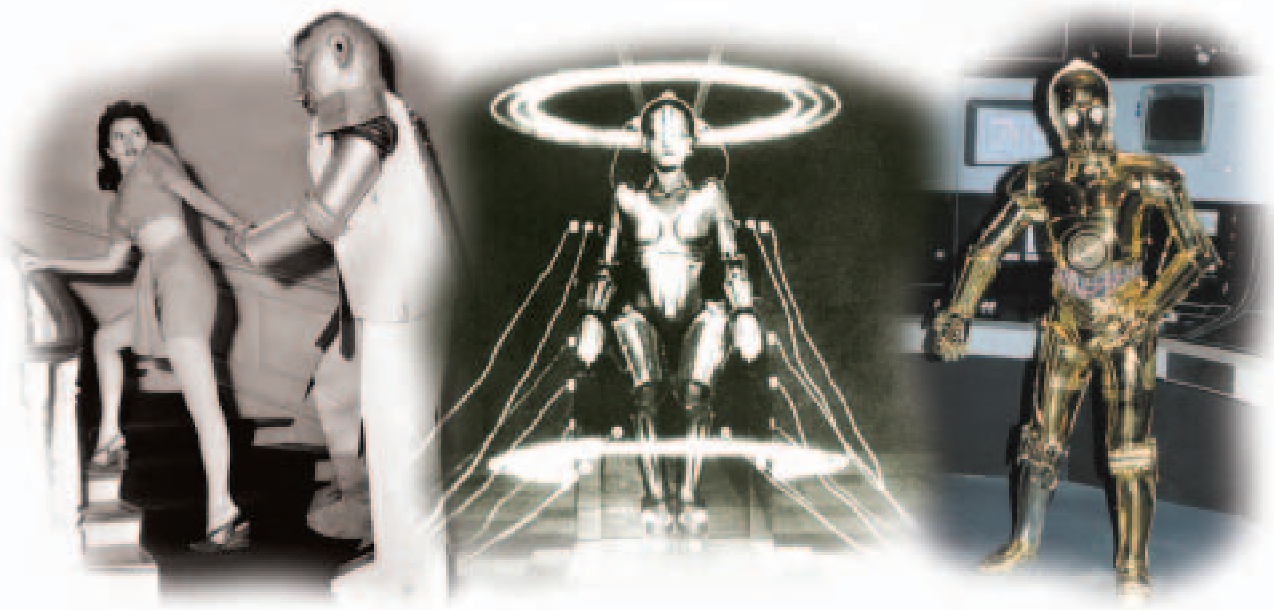

Figure 3.16 Some movie robots

Figure 3.17 Assembly-line robots weld car bodies together in an automobile factory.

Changing Society—Changing Technology

The drive to develop more effective and efficient robots came from the need to replace humans in different tasks. In the past, people had been willing to work for low pay and carry out boring or dangerous tasks. However, by the middle of the 20th century, people were demanding better wages and better working conditions. As wages went up, industry looked for ways to replace humans in manufacturing and other applications. Robots were the answer.

An industrial robot that welds car parts together, for example, works faster and more efficiently than any human. But it doesn't look anything like a human. It doesn't need a head, torso, or legs to do its job. All it needs is an arm. In fact, most industrial robots today are nothing more than "smart" arms.

Anatomy of a Robot

Robots are extremely complex devices and vary widely in appearance, depending on the job they're designed to do. However, a very simple robot contains some or all of the following basic parts:

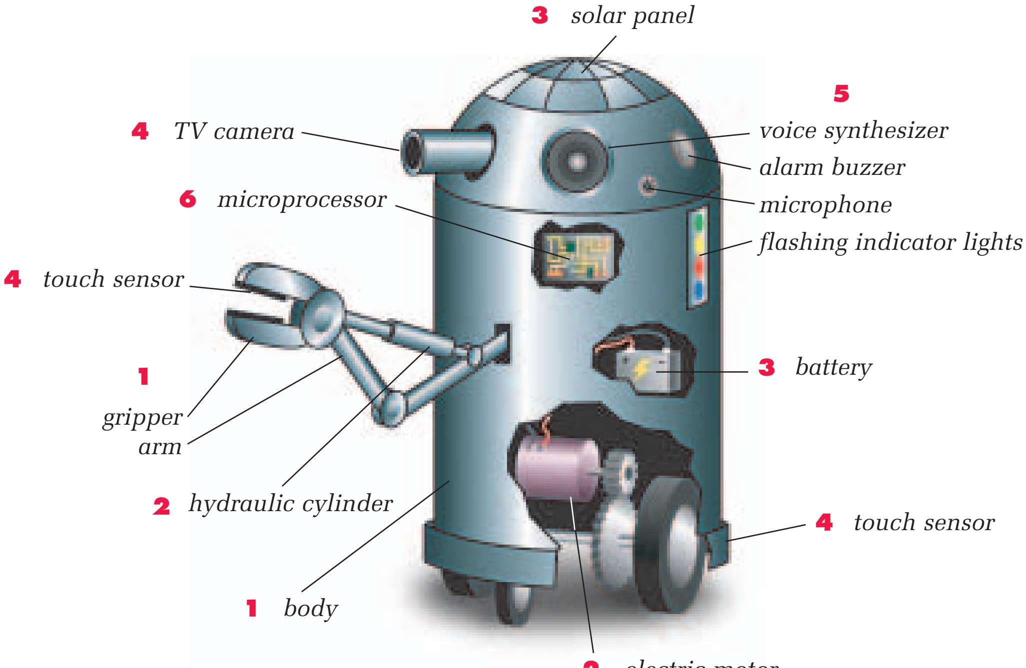

Figure 3.18 A simple robot

1 Body: steel, aluminum, or plastic. Metal rods are used for arms. Simple grippers that open and close are used for hands. Wheels are used for movement.

2 Motor Devices: electric motors and hydraulic or pneumatic cylinders. They move the robot's arms and wheels.

3 Power Source: battery or solar cells.
4 Sensors: detect light, sound, pressure, and heat. They tell the robot about the outside world.
5 Output Devices: buzzers, flashing lights, or synthesized speech. They enable the robot to communicate.
6 Microprocessor: minicomputer that acts as the robot's brain. It receives signals from the robot's sensors and decides what actions to take. It sends instructions to the robot's output devices or motor devices.

Changes in the Environment Result in New Technology

Space exploration is a fascinating area of technology, but it does not affect very many people directly. The environment here on planet Earth does. Since the early 1960s, people have become more aware of their impact on the environment. The increasing human population and the use of certain technologies have damaged the environment. Chemicals have polluted water in lakes, rivers, and streams. Exhaust from cars and other vehicles has polluted the air.

People observed the changes in the environment and realized that new technologies were needed to prevent more damage. One example is the development of recycling technologies. These include new mechanical devices for processing materials so they can be used again or in a different form. Another example is the development of new materials, such as biodegradable plastic that breaks down much faster than ordinary plastic.

New technologies can help protect the environment from damage. Figure 3.19 shows a skimmer device used to clean up oil spills in water.

Figure 3.19 Oil floats on water, so clean-up crews can use skimmers such as this one to skim oil off the water's surface.

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Flying High

The first scheduled aircraft passenger service began in 1909. Passengers were carried by large, lighter-than-air craft called *zeppelins*. These lighter-than-air vehicles flew slowly but could travel long distances. So why are we not flying in zeppelins today? Use the Internet or your library to find out how passenger airplanes have developed through the years.

- How have new materials and other technologies affected the development of passenger airplanes?
- What role has the process of trial and error played in the development of passenger airplanes?

CHECK AND REFLECT

1. Look back at Figure 3.14 on page 315, which shows some of the stages in the development of the sewing machine. How do you think each of the following affected sewing machine development?
   a) advances in science
   b) advances in other technologies
   c) changes in society
2. Give an example of the role that trial and error can play in technology development. You can use an example from your reading in this section or any other example you know about.
3. Do you think cars will use the same kind of engine in the future as they do now? Why or why not?
4. Describe two ways that the environment could affect the development of new technology.

Careers and Profiles

INVENTOR

Canadian Peter L. Robertson (1879–1951) invented the Robertson square-headed screw in Milton, Ontario. The new square design prevented screwdrivers from slipping off the screw head as easily as they did with other screws. In 1908, he set up the Recess Screws Limited factory to manufacture the new screw. Now known as Robertson Inc., the plant is still busy turning out Robertson screws.

Figure 3.20 Peter Robertson

Most successful inventors will tell you that they started developing their natural curiosity at an early age. They took things apart to see what made them work. They constructed gadgets using toy building sets. They participated in science fairs. And in school, they took a variety of science, math, and engineering courses.

1. Have you ever thought of inventing something? If so, what was it and did it work?
2. What do you think would be the most difficult part of being an inventor?
3. Why do you think both ordinary screws and Robertson screws are used—why not just one kind?

Assess Your Learning

1. Define in your own words the terms *design* and *function* as they are used to describe mechanical devices.
2. If you were buying a blow dryer, you might use criteria such as the following to choose one:
   - It has to cost less than $20.
   - It has to have at least two speed settings (high and low) and two temperature settings (hot and warm).
   - It has to have adjustable electrical settings so it can be used on other continents.
   - It has to be foldable for easy packing.

   Imagine that you are a professional hair stylist, buying a blow dryer to use at work. Would you use the same list of criteria? Explain your answer.
3. Describe three reasons why people invent new machines or products.
4. What impact could the following discoveries have on a machine? Use an example of a machine in your answer.
   a) the development of new types of materials
   b) the development of new sources of energy

Focus On SCIENCE AND TECHNOLOGY

The goal of technology is to provide solutions to practical problems. The development of good technology depends on solid scientific knowledge. It also depends on evaluating prototypes and designs to improve how they function. Think back to what you learned in this section.

1. What were some examples of the link between science and technology that you read about in this section?
2. What are some factors you would have to consider if you invented a new machine that you wanted people to use?
3. Why are machines and other products constantly being evaluated?

Living with a Machine

The Issue

Imagine that a large new machine has been developed. It will transport up to six people in all kinds of weather for short or long distances. It will provide jobs for millions of people in everything from mining to manufacturing to servicing. However, it will also have the following impacts:

- It will pollute the air wherever it is used.
- It will affect the entire Earth by contributing to the "greenhouse effect."
- It will kill thousands of people every year in accidents.
- Its operation will require that millions of square kilometres of the environment be paved over, destroying habitat for animals and plants.
- It will kill thousands of animals every year.
- Its manufacturing and operation will require large amounts of non-renewable resources—metals and petroleum products.

Of course, this information describes the cars and other vehicles that we rely on today.

Now, when brand new technologies are developed, people try to identify such effects. They can then prevent the effects from happening or reduce the possible harm they could cause. But what do we do with existing technology such as the car?

Efforts are being made to reduce the harmful effects of cars. Research continues on ways to make cars more energy efficient and less polluting. In some areas, cars carrying more than two people are given special lanes to promote car pooling. Cars are being made safer with the use of airbags and other features.

What do you think should be done to reduce the harmful effects of cars? Use the following suggestions to find out more about what can be done about cars.

Cities such as Calgary have large areas covered in highways. This allows easy movement of cars. But the pavement destroys the natural environment, increases temperatures locally, and causes increased runoff of water polluted by oil and other chemicals.

Go Further

Now it's your turn. Look into the following resources to help you form your opinion:

- Look on the Web: Check the Internet for information on new car technology and how cities are dealing with cars.
- Ask the Experts: Try to find an expert, such as a city planner, a traffic engineer, or an engineer who works on car engines or design.
- Look It Up in Newspapers and Magazines: Look for articles about engine technology, car body design, and the environmental impact of cars.

In Your Opinion

- Where should new technology development for cars focus?
- Should the use of cars be restricted?
- Should we be concerned about the impact of new technology on people and the environment? Explain your answer.

Key Concepts

1.0

- systems and subsystems
- transmission of force and motion
- simple machines

1.0 Machines are tools that help humans do work.

- A machine is a device that helps us do work. Machines use energy from animals, people, electricity, and fossil fuels to produce motion.
- There are six types of simple machines: the lever, inclined plane, wedge, screw, pulley, and wheel and axle.
- Complex machines are made up of two or more simple machines. Gears, linkages, and transmissions connect subsystems and help to transmit force in complex machines.

2.0

- mechanical advantage, speed ratios, and force ratios
- mechanical advantage and hydraulics
- measurement of work in joules

2.0 An understanding of mechanical advantage and work helps in determining the efficiency of machines.

- Mechanical advantage is a measure of how much a machine can increase an applied force. The speed ratio describes how the speed of an object is affected by a machine.
- Work is done when a force acts on an object to make the object move. Machines help us do work by transferring energy. Work input and work output are not equal in the real world because of friction.
- Efficiency is a measurement of how well a machine or device uses energy. It is usually given as a percentage. It can be calculated by dividing the mechanical advantage by the speed ratio and multiplying by 100. This is a quantitative description of efficiency. No machine can be 100% efficient.
- Hydraulic systems use a liquid to transmit force in a closed system of tubes. They work because of Pascal's law. These systems can have a large mechanical advantage because of the difference in the sizes of the pistons used.

3.0

- design and function
- social and environmental impacts

3.0 Science, society, and the environment are all important in the development of mechanical devices and other technology.

- Function and design are two important aspects of mechanical devices. Function is what the device is supposed to do. Design is the physical form of the device that makes it usable.
- The main factors that should be included in an evaluation of a mechanical device are: efficiency, effectiveness, and impact on humans and the environment.
- Efficiency can also be described qualitatively. A machine or device is efficient when it helps you do a task quickly and easily.
- Technology development is influenced by scientific knowledge, trial and error, and changes in society and the environment.

PROJECT

BUILDING A MECHANICAL HAND

Getting Started

At the beginning of this unit, you drew a design for a device to solve the problem of retrieving a robotic explorer that had become wedged in a drainage pit. After you designed the device, you studied simple machines, gears, and hydraulic systems. Now it's time to put all that information to use.

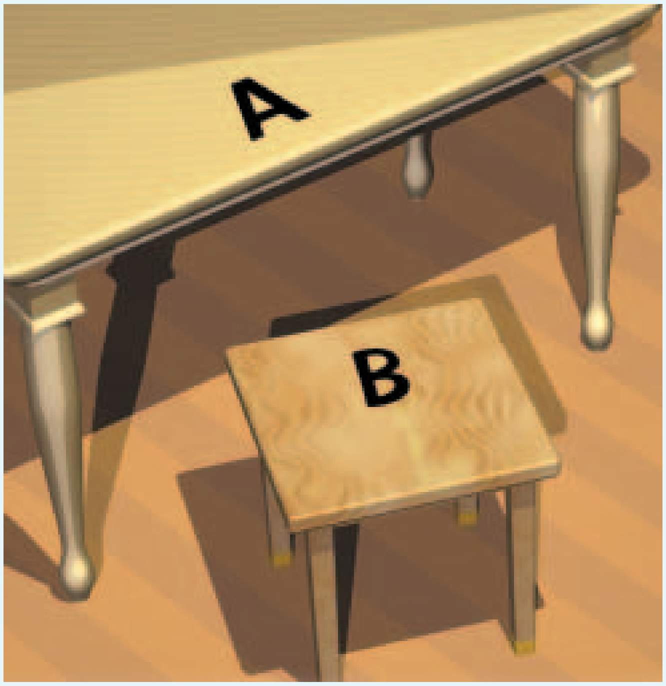
If you did not design a mechanical device to remove a robotic explorer from a drainage pit earlier in this unit, you should do that activity now. If you have completed this activity, collect your notes and designs and organize them in a manner that makes sense to you. Review your results with your partner or group.

Your Goal

Redesign the gripper device you designed earlier, and construct a working model of it.

What You Need to Know

Your teacher will show you the model of the drainage pit where the robotic explorer is located. It will look something like the picture on page 256. Note that in the earlier activity you assumed that the robotic explorer had a mass of 100 kg. For this activity, you can choose the mass of load that will work with your model.



Place gripper device at A and load to be lifted at B.

Steps to Success

1 Review your original design drawings and make modifications to improve your design.

2 Create a plan that describes how you will build your gripper device. Include in your plan a list of the materials you will need.

3 Show your plan to your teacher for approval. Revise your plan based on your teacher's comments.

4 Build your device and test it.

5 Demonstrate your device to the class.

6 Observe how your classmates' devices work. Record any ideas you think you could incorporate into your device.

How Did It Go?

7 What worked well in your gripper device?

8 What would you modify so your device would work better next time?

9 What were some of the limitations you faced when you built your device? For example, did you have enough time?

10 Which device out of all of those made by your class do you think worked best? Explain your answer.

11 What are some possible applications of your gripper device?

Unit Review: Mechanical Systems

Unit Vocabulary

1. Create a concept map that illustrates the relationships between the following terms. Begin your concept map with the phrase *mechanical systems*.

simple machine	friction
complex machine	work
subsystem	efficiency
mechanical advantage	hydraulic
speed ratio	pressure

Check Your Knowledge

1.0

2. Why are machines useful?

3. What is the difference between a simple machine and a complex machine?

4. Identify four simple machines, and describe the advantages of each one.

5. a) What is a subsystem in a complex machine?

b) Identify as many subsystems as you can in the robotic dog shown in the drawing below. For each one, explain why it is a subsystem.

Question 5b) Sparko, the robot dog

6. What is the purpose of the transmission in a car?

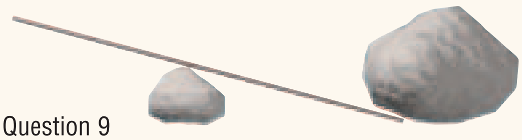
7. What type of simple machine is in each item below?

bottle opener	hammer
your jaw	roller blades
shovel	screwdriver

2.0

8. Describe three effects of simple machines and give one example for each.

9. A lever is made out of a long pole and a rock, as shown in the diagram here. How would you change the location of the rock to increase the lever's mechanical advantage?



Question 9

10. A sailor uses a force of 600 N to pull on a pulley system to raise sails on a boat. The maximum weight of sails that the sailor can raise with this system is 2400 N. What is the mechanical advantage of the pulley system? (Hint: The weight of the sails is the same as the pulley's output force.)

11. Heavy equipment operators use a joystick to control the hydraulic arms on front-end loaders. When the joystick is moved forward 3 cm, the hydraulic arms move 4 m. What is the speed ratio of the front-end loader?

12. What is the difference between force and work?

13. Three students have built a prototype of a mechanical device to move gym equipment from the storeroom into the gym. They test their prototype and measure the forces and distances. They use their measurements to calculate the work done. They find that the work input and work output are equal. Is their calculation correct? Explain your answer.

14. Engineers are working to develop new car engines that are up to 60% efficient. What does "efficiency" mean in this example?

15. Why do hydraulic systems usually have large mechanical advantages?

3.0

16. *The development of new technology can be a process of trial and error.* Explain the meaning of this statement. Use an example to support your explanation.

17. Why is it important to know how to evaluate mechanical devices? Use the following words in your answer: efficiency, effectiveness, impacts on people and the environment.

18. We often see the words "science" and "technology" used together. Describe in your own words the relationship between the two terms.

19. A new type of one-person motorized vehicle has been developed. It is about the size of a motorcycle but you sit in it like a car. List some of the social and environmental issues that should be considered when this machine is evaluated.

Connect Your Understanding

20. The food at the grocery where your family shops arrived there by truck. But it may have arrived in your community—before it got to the store—by truck or train or air.

a) Describe two ways in the past that people transported goods.

b) Why do you think so many different ways of transporting goods have been developed?

21. What do you think would happen to a car's braking system if a hole developed in one of the brake lines? Use the words "force" and "pressure" in your answer.

22. List two examples of machines that use both hydraulic systems and levers. Why do you think hydraulic systems are used in each example?

23. You are delivering a large box of erasers to the back of a store. At the loading dock, you can lift the box a distance of 1 m onto the dock. This requires a force of 10 N. Or you could push the box up a ramp 4 m long. This requires a force of 2.5 N.

a) Which method of raising the box requires more work? Include your work calculations in your answer.

b) Which method do you think would be easier? Why?

24. The ride-on lawn mower like the one in the photo is a small tractor.
a) Make a list of criteria that could be used by a family trying to decide whether to buy one of these mowers.
b) What factors, other than cost, might affect a family's decision to choose this type of mower instead of another type of lawn mower? (Other types of lawn mowers include the push mower without any motor, the electric mower, and the gasoline mower.)

25. Imagine you were listening to an inventor in the 1800s describe his development of the internal combustion engine. (This is the type of engine used in cars and other vehicles today.) During the discussion, you realize he hasn't considered any of the social or environmental issues associated with the engine. Why do you think the inventor ignored those aspects of his invention?

Practise Your Skills

26. Draw a design for a catapult device that could launch a golf ball over a small tree. The catapult should include at least two simple machines and a hydraulic system.

27. Plan an experiment to measure the mechanical advantage and speed ratio for a stapler.
a) What materials would you need?
b) What procedure would you use?
c) What variables would you need to control?

Self Assessment

28. Describe what you found most interesting about studying mechanical systems in this unit.

29. Describe one issue or idea in this unit that you would like to explore in more detail.

30. What part of the unit did you find most difficult? What could you do to improve your understanding of that part?

31. What major factors will you consider the next time you want to buy a mechanical device of some kind?

Focus On — Science and Technology

In this unit, you have investigated science and technology related to mechanical systems. Consider the following questions.

32. Reread the four questions on page 257 about the science and technology of mechanical systems. Use a creative way to demonstrate your understanding of one of the questions.

33. Describe a situation where a machine was invented to meet a specific human need.

34. Describe an example of how advances in science contributed to the development of new technology.

35. Describe two ways that the environment can affect the development of mechanical devices.