

The Mechanical Advantage of Machines



CORBIS/GALEN ROWELL

The mechanical advantage of a pulley system makes it possible for these men to lift an overturned truck.

INTRODUCTION

In Lessons 11 through 13, you investigated three kinds of simple machines. You saw that machines make work easier by reducing the effort force needed to do the work. Is one machine better than another? How can you compare different machines? And does the same machine work equally well under different conditions? In this lesson, you will explore these questions and learn one way to compare machines. In Lesson 15, you will learn another way to compare them.

OBJECTIVES FOR THIS LESSON

Calculate the ideal mechanical advantage of inclined planes and pulley systems.

Calculate the actual mechanical advantage of inclined planes and pulley systems.

Compare actual and ideal mechanical advantage.

Getting Started

- 1.** Suppose someone asked you, Which is the best machine: an inclined plane, a pulley, or a lever? Answer the question in your science notebook. Explain how you would decide which is the better machine. Be prepared to share what you wrote with the class.
- 2.** Read “Mechanical Advantage,” on pages 132–133.
- 3.** In your science notebook, describe the difference between ideal and actual mechanical advantage.
- 4.** Discuss with the class why someone would want to know the mechanical advantage of one machine over another.

MATERIALS FOR LESSON 14

For you

- Your copy of Student Sheet 11.2: What Is the Work Done Using an Inclined Plane?
- Your copy of Student Sheet 12.1: How Is a Pulley System Used To Do Work?
- 1 copy of Student Sheet 14.1: The Mechanical Advantage of Machines

MECHANICAL ADVANTAGE

One way to compare machines is to calculate their mechanical advantage. A machine has two kinds of mechanical advantage—ideal and actual. What is the difference? Ideal mechanical advantage tells how much the machine *increases the effort distance* when doing work. Actual mechanical advantage tells how much the machine *reduces the effort force* when doing work, as shown in the following example.

Suppose a machine has an ideal mechanical advantage of 4.0. What does that mean? It means the effort distance needed to raise a load must be 4 times greater than the load distance. As you know, the load distance is how high you want to lift an object—a sled, for example. If you wanted to lift the sled 0.10 meter, you would have to exert an effort force over a distance of 0.40 meter.

Now suppose that same machine has an actual mechanical advantage of 3.0. That means it would take 4.0 newtons of force to lift a load that weighs 12.0 newtons. Another way to describe actual mechanical advantage is to say that the machine increases effort force by a factor of 3.

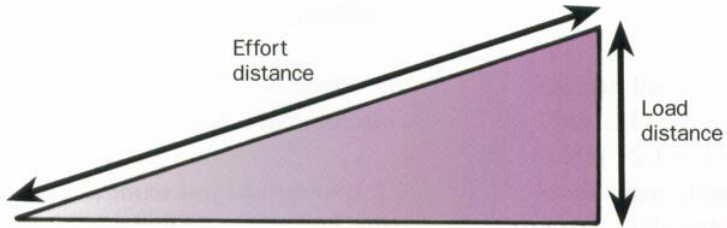
Mechanical advantage is based on what you learned in the previous lessons: Machines reduce effort force and increase effort distance. In this example, the actual mechanical advantage is less than the ideal mechanical advantage calculated for the same machine. Can you think of a reason why?

As earlier investigations showed, machines can be set up in different ways. Each setup has two kinds of mechanical advantage—ideal and actual. In this lesson, you will calculate the ideal and actual mechanical advantage for different setups of the inclined plane and the pulley systems that you made in Lessons 11 and 12. To accomplish this, you will perform calculations based on the following equations:

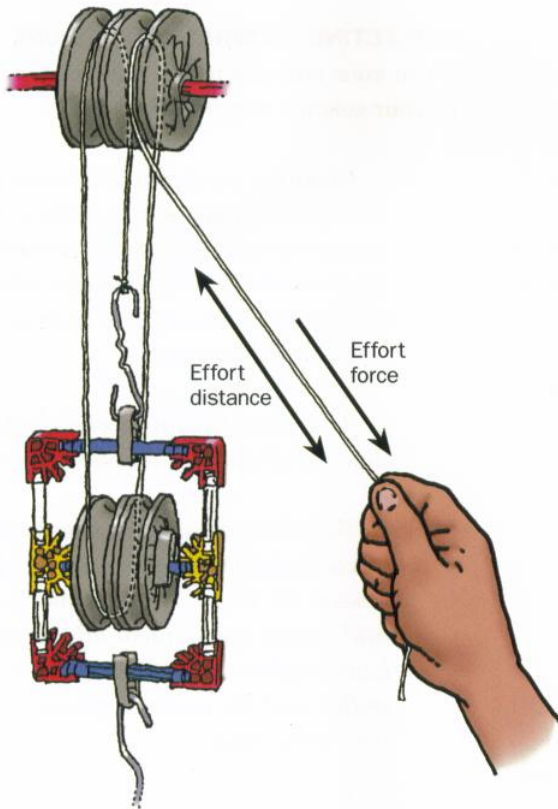
$$\text{Ideal mechanical advantage} = \frac{\text{Effort distance}}{\text{Load distance}} = \frac{\text{Effort distance}}{\text{Distance lifted}}$$

$$\text{Actual mechanical advantage} = \frac{\text{Load force}}{\text{Effort force}} = \frac{\text{Sled weight}}{\text{Effort force}}$$

Look at the two illustrations—one of an inclined plane and one of a pulley—for a review of how to measure forces and distances on an inclined plane and a pulley.



Effort distance and load distance on an inclined plane



Effort force and effort distance in a pulley system

Inquiry 14.1

Calculating Mechanical Advantage

PROCEDURE

1. Use the effort distance and load distance data you collected in Inquiry 11.2 and recorded on Student Sheet 11.2 (Table 1) to calculate the ideal mechanical advantage for each inclined plane slope. Record your data and calculations in Table 1 on Student Sheet 14.1: The Mechanical Advantage of Machines.
2. Use your effort force and load force data on Student Sheet 11.2 to calculate the actual mechanical advantage for each plane slope. Record your data in Table 2 on Student Sheet 14.1. Then use the blank graph on the student sheet to graph actual mechanical advantage versus slope of the incline.
3. Answer the following questions in your science notebook:
 - A. Which slope has the largest actual mechanical advantage?
 - B. Which slope has the largest ideal mechanical advantage?
4. Use the data you collected in Inquiry 12.1 and recorded on Student Sheet 12.1 to calculate the ideal mechanical advantage and the actual mechanical advantage for the pulley systems you assembled. Record your data in Tables 3 and 4 on Student Sheet 14.1.

5. In your science notebook, answer the following questions based on your data for pulleys:

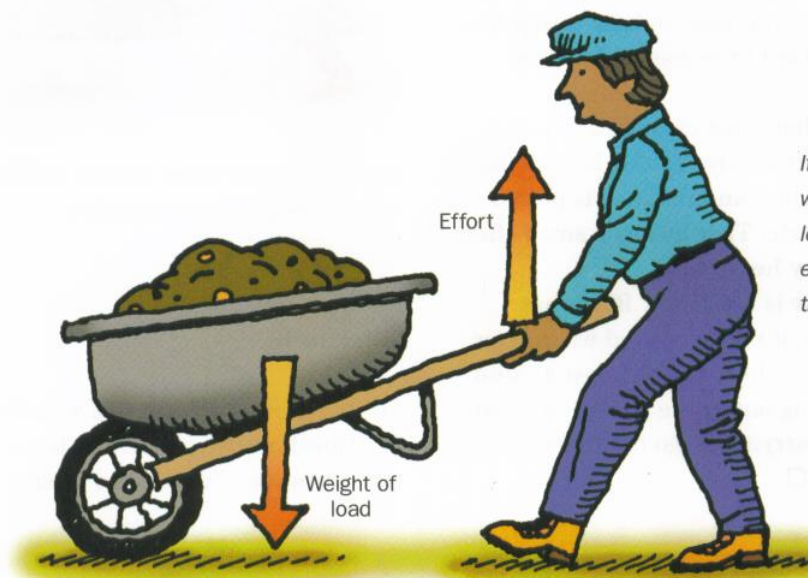
- A. Which pulley had the greatest ideal mechanical advantage?
- B. Which had the smallest actual mechanical advantage?
- C. Why would you want to use a pulley that had a small mechanical advantage?

REFLECTING ON WHAT YOU'VE DONE

Write your answers to the following questions in your science notebook:

- A. Examine mechanical advantage for the inclined planes and pulleys. What pattern do you see when comparing ideal mechanical advantage with actual mechanical advantage? How can you explain the pattern?
- B. What does actual mechanical advantage tell about a machine's usefulness?
- C. You did not calculate mechanical advantage for the levers you studied in Lesson 13. How do you think the ideal and actual mechanical advantages of the lever might compare with those of the pulley and the inclined plane? Explain your reasoning.

Secret Wheelbarrow Technology



If the handles of this wheelbarrow were longer, would it be easier or harder to lift the load? Why?

The wheelbarrow is not a fancy machine. It is basically a second-class lever. The axle of the wheel is the fulcrum, the lifting effort is applied to the ends of the handles, and the load is in between.

People in Western Europe have used wheelbarrows for at least 700 years. The earliest record of a wheelbarrow's use in Western civilization is found in a stained-glass window of Chartres Cathedral in France, which was built in the early part of the 13th century.

Wheelbarrows at War?

But don't be fooled—wheelbarrows have been around for much longer than this! Wheelbarrows were being used in China at least a thousand years before they appeared in the window of the Chartres Cathedral. In these early years, instructions on how to build them were closely guarded.

Why? Because wheelbarrows were the Chinese military's secret weapon. Some wheelbarrows were used to carry officers; others were used to transport military equipment or food. Armies in China had special "wheelbarrow brigades," much as modern armies have tank brigades. One job of the wheelbarrow brigades was to support armies who were fighting in hilly terrain where other vehicles couldn't go.

The Chinese even used wheelbarrows to protect the foot soldiers from those who were mounted on horses. Hundreds of wheelbarrows were used to make protective barriers around an army camp—much like the settlers in America made a circle of wagons to protect themselves from attack.

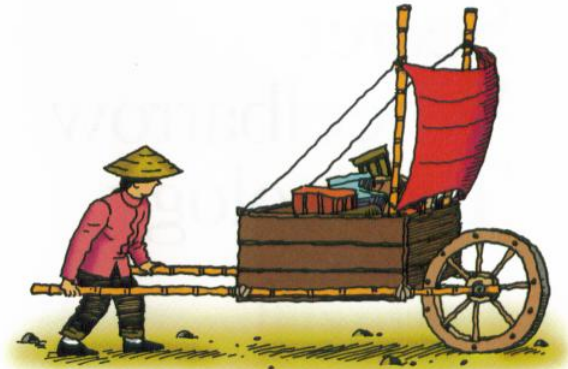
Wheelbarrows at Peace

Today, the wheelbarrow has been put to use for peaceful purposes. For example, it is one of the gardener's essential tools. Modern wheelbarrows come in a variety of forms and sizes, each appropriate for a specific task.

Traditional wheelbarrows, which function as second-class levers, are used to haul things like dirt around your yard or bricks around construction sites.

Wheelbarrows that must carry heavy loads are constructed differently. The wheels are farther from the handles, and the load is placed directly over the axle. That means a small effort force can lift a very heavy load.

The wheelbarrow is not fancy. But it has quite a history. So, if you get bored when your mother asks you to wheel the compost around while you're helping out in the garden, just pretend that you're carrying cargo for an ancient Chinese warlord! □



Too hard to push? Some Chinese wheelbarrows had sails that helped move them along.

QUESTIONS

1. What class of lever is a wheelbarrow?
2. How have wheelbarrows been used over the centuries? Summarize briefly.

AP/WIDE WORLD PHOTOS



Wheelbarrows can even carry people.

MORE SIMPLE MACHINES:

The Wedge, Screw, and Wheel and Axle

In Lesson 11, you explored the inclined plane, which is one type of simple machine. In Lessons 12 and 13, you learned about the pulley and the lever, two other types of simple machines.

There are six simple machines in all. The other three are the wedge, the screw, and the wheel and axle. Each of them has things in common with the three simple machines you've explored in class. They all can make work easier by reducing the effort force to do a job while increasing the effort distance. A small effort force gets a big result.

The Wedge

Like a lever, a wedge magnifies force. Like an inclined plane, a wedge is used to move one object in relation to another object. But while an inclined plane is used to move an object along a surface, a wedge is used to move an object into, or even through, an object.

The simplest form of wedge is a chisel. A chisel is one of oldest machines known to humankind.

An ax is a wedge with a handle. Think about what happens, for example, when you use an ax to split a log. If you can supply sufficient force (and that's not easy!), the log will split into two pieces. But what has happened from the viewpoint of physical forces?



A wedge can be used to split wood.

The ax blade is a wedge that has two inclined planes (one on each side of the blade). When you hit the log with an ax, the force you exert pushes the blade of the ax into the log. This forces the wood on both sides of the ax up the inclines and results in a large sideways force that pushes the wood apart, bit by bit. Repeat the motion enough times, and you will split the log.



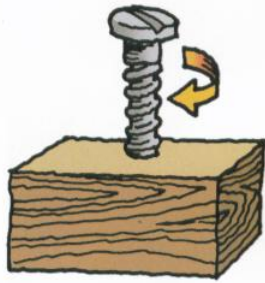
CORBIS/MARIL WEATHERLY

Ice climbers rely on wedges to chip into the ice and hold on.

Axes have other uses. For example, ice climbers drive the blade of an ice ax into the ice. The ice moves apart as the ax makes a narrow wedge in it. After that, the ax is held in place by friction and by sharp teeth along the edge of the blade. Climbers use ice axes while they are making their way up a slope. These axes provide a much stronger grip than bare hands do.

The Screw

A screw is an inclined plane wrapped around a cylinder. When you turn a screw, you move material up an incline. A screw can be used to lift an object or to fasten one object to another.



The screw is another example of a simple machine.

A screw magnifies the driving (or lifting) force. It has to be rotated a fair distance before it will move forward a short distance.

Think about what happens when you put a screw into a piece of wood. It takes a lot of turns! That means your small effort force to turn the screw acts through a large effort distance. Each time you turn the screw, it moves a small distance into the wood with a large force.

Screws are versatile. They can even be used to lift water. Archimedes' screw is a famous invention of ancient times. It was used to raise water from wells to irrigate fields. The device consisted of an inclined plane, in the shape of a screw, that is mounted inside a tight-fitting cylinder. When the operator turned a handle at the top of the screw, water could be raised with much less effort than would be required to lift it directly.

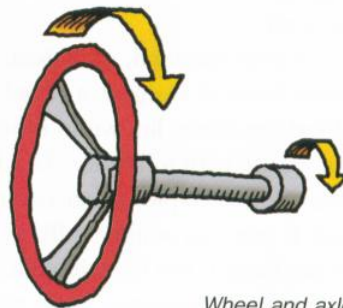


CORBIS/ALAN TOWSE; ECOSCENE

Archimedes' screw is still used today. Here an Archimedes' screw moves plastics through a modern recycling plant.

Wheel and Axle

The wheel and axle works like a lever that rotates 360 degrees around a fixed point. The magnification of force occurs because of the



Wheel and axle

difference in size between the wheel and the axle. The larger the wheel compared with the axle, the greater the distance the edge of the wheel moves compared with the edge of the axle. Because the wheel moves a great distance compared with the axle, the force needed to move the wheel is small compared with the force exerted by the axles.

Whenever you turn on a water faucet, you are using a wheel and axle. You apply a small force at the outside of the faucet handle to turn it. This small force creates a larger force on the axle and opens a valve, causing water to flow. Like all machines, the wheel and axle make it possible for a small force to do the work of a large force.

Wheels and axles are used in many other devices, such as can openers, bicycles, and clocks. Some are easy to see; others work behind the scenes. Regardless of whether you see it or not, if machines are turning, wheels and axles are probably at work. □

FOR FURTHER CONSIDERATION

You may want to visit the STC/MS Web site, <http://www.stems.si.edu>. There you will find links where you can learn more about simple machines.



CORBIS/RICHARD T. NOWITZ

Wheels and axles are used to turn valves of all sizes on and off.