LESSON 15

The Efficiency of Machines

CORBIS/MICHAEL S. YAMASHITA

A more efficient train? This train uses magnetic levitation to reduce friction between the train and the tracks. Its sleek design also reduces air friction (drag). Reducing friction enables the train to travel efficiently at high speeds.

INTRODUCTION

In Lesson 14, you learned how to calculate the mechanical advantage of a machine. You found that a machine with a large mechanical advantage can enable a small effort force to lift a heavy load. Does that mean the machine is also efficient? What does it mean for a machine to be efficient? How would you measure efficiency? In this lesson, you will have a chance to learn how efficient your inclined planes and pulleys are.

OBJECTIVES FOR THIS LESSON

Learn to calculate the efficiency of different machines.

Calculate the efficiency of inclined planes and pulley systems.

Compare the efficiency of an inclined plane when the slope of the incline is changed.

Compare the efficiencies of different pulley systems.

THE MEANING OF EFFICIENCY

The word "efficiency" is used to describe the work you get out of a machine compared with the work you put into that machine. An efficient machine puts out a lot of work when compared with the work put into it. On the other hand, if you put a lot of work into a machine and get very little work out of it, then you would say the machine is not very efficient, or it is "inefficient."

To calculate the efficiency of a machine, you divide the output work by the input work, as shown in the following equation:

$$\text{Efficiency} = \frac{\text{Output work}}{\text{Input work}} = \frac{(\text{Load force} \times \text{Load distance})}{(\text{Effort force} \times \text{Effort distance})}$$

Scientists often describe efficiency using percentages; for example, a machine might be described as being "30 percent efficient." That means that the output work is 30 percent of the input work. To calculate efficiency as a percentage, use this equation:

$$\text{Efficiency (\%)} = \frac{\text{Output work}}{\text{Input work}} \times 100\%$$

How does the efficiency of various machines compare? The table below shows the efficiency of different machines, motors, and other things. What is the maximum efficiency that a machine can have? What would that mean? Think about these questions as you work through this lesson.

Efficiencies of Some Common Devices

Item	Efficiency (useful output energy/input energy) (%)
Incandescent lightbulb	5
Automobile engine (gasoline)	25
Nuclear power plant	30
Small electric motor	63

MATERIALS FOR LESSON 15

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 15.1: The Efficiency of Machines

Getting Started

1. Discuss with the class why someone would want to know the efficiency of a machine.

2. Read "The Meaning of Efficiency," on page 141.

Inquiry 15.1
Calculating Efficiency

PROCEDURE

1. You will use the data you collected in Lessons 11 and 12 for this lesson. Use the load force and load distance data that you recorded on Student Sheet 11.2 to calculate the output work when moving the sled up the inclined plane. Enter this measurement into the column for "Output Work" in Table 1 on Student Sheet 15.1.

2. In Table 1 on Student Sheet 15.1, record the input work for four different slopes of the inclined plane. To do this step, use the "Work" column in Table 1 on Student Sheet 11.2.

3. Use the input work and output work information that you have entered in Table 1 and calculate the efficiency of the incline for each slope. Express your answer as a percentage.

4. Answer this question in your science notebook:

   What can you conclude about the efficiency of the inclined plane that you used in Lesson 11?

5. Now use the data collected on Student Sheet 12.1 to calculate the efficiency of the pulley systems. Record your calculations in Table 2 on Student Sheet 15.1.

6. Answer this questions in your science notebook:

   On the basis of your data for pulleys, which pulley arrangement is the most efficient?

REFLECTING ON WHAT YOU'VE DONE

Answer the following questions in your science notebook. Be prepared to discuss your answers with the class.

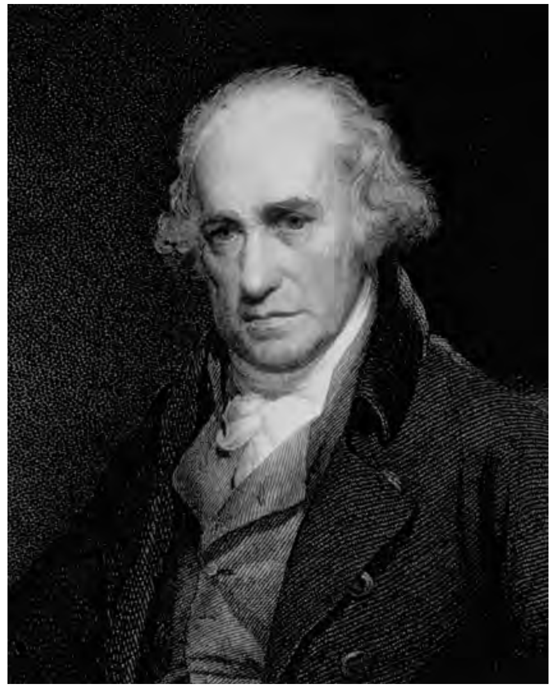
A. Examine the efficiencies for the inclined planes and pulleys. Do you see a pattern? How can you explain it?

B. You did not calculate the efficiency for the levers in Lesson 13. What do you think this efficiency would be like? Explain your reasoning.

C. Which would you rather have, a machine with a great mechanical advantage or a machine with high efficiency? Why?

Harnessing the Power of Nature

James Watt and the Steam Engine



COURTESY OF THE LIBRARY OF CONGRESS

James Watt (1736–1819)

During the mid- to late-18th century, workers in Western Europe and America began using power-driven devices in place of hand tools and simple machines. This change in the use of power, known as the Industrial Revolution, had an important impact on people's lives. It was as important as any political upheaval such as the American or French Revolution.

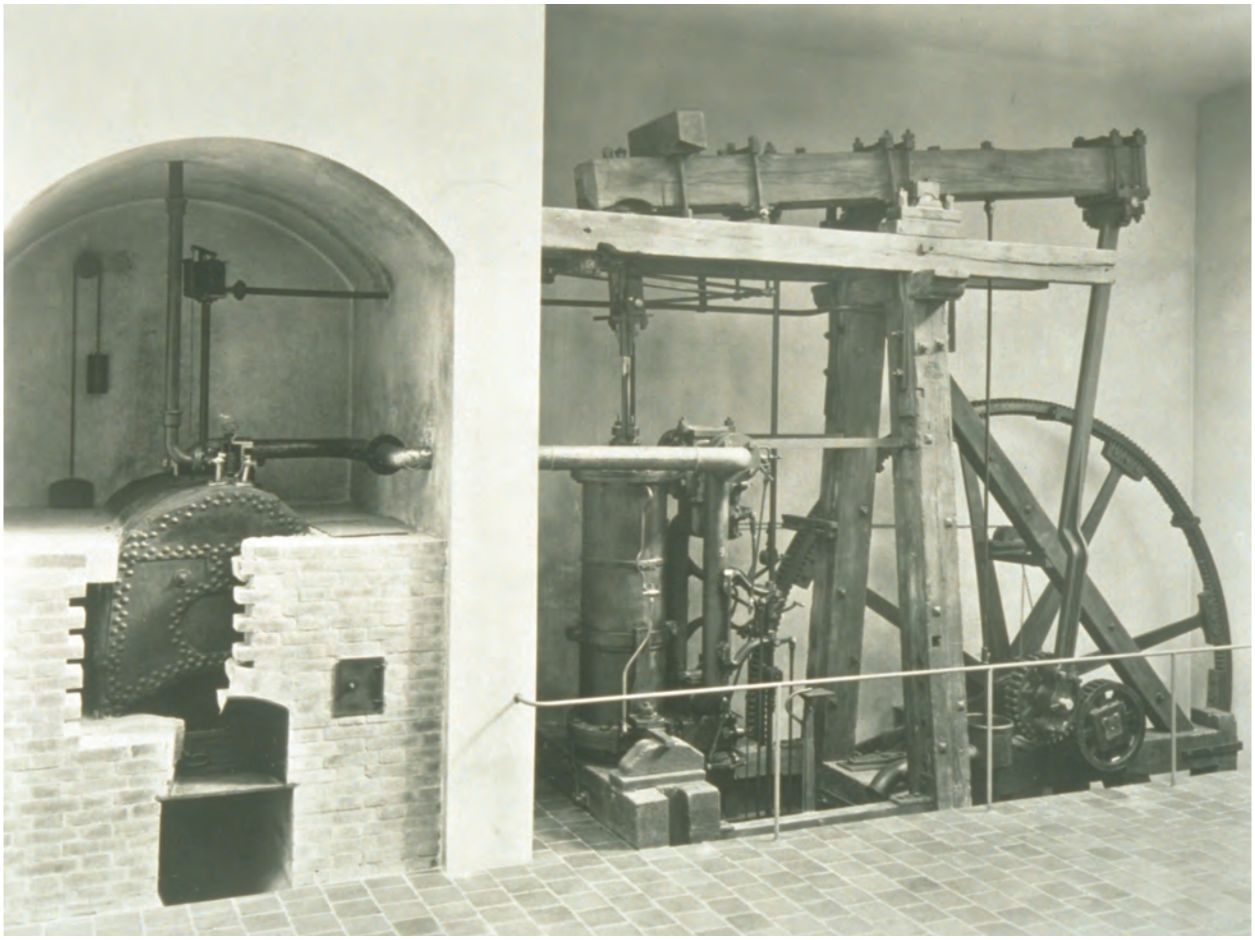
Scientists and inventors played an important part in the Industrial Revolution. Their inventions made major changes in society, which then changed its view of the scientist. No longer was the scientist a natural philosopher and observer; after the Industrial Revolution, the scientist became a public figure whose work affected society.

James Watt represents the link between experimental science and its technological application. Watt's improved steam engine had a major influence on transportation, communication, and industry; thus, it was one of the most far-reaching inventions of the Industrial Revolution.

Watt was born in Scotland in 1736. His education was both classical and practical. He studied Greek, Latin, and mathematics *and* worked on model making in his father's carpentry shop. After an apprenticeship in constructing mathematical instruments such as quadrants, compasses, and scales, Watt opened his own shop in Glasgow. Shortly thereafter, he was able to examine and test the Newcomen steam engine acquired by the University of Glasgow.

The Newcomen engine, devised by Thomas Newcomen in 1712, used steam—and its expansion and compression—to move a piston back and forth. The piston was connected to a pump that pumped water from coal mines. Newcomen's engine was both primitive and inefficient; it required a large amount of fuel (coal) to generate the steam that drove the piston's motion.

Watt began experimenting with the size of the boiler and its connections to make a more efficient engine. He eventually moved the condensing chamber away from the boiling chamber so that the chambers could be kept hot all of the time. Periodically, Watt had to stop his inventing to return to surveying to earn enough money to support his family. He did, however, secure patents on his improvements and teamed up with a wealthy British merchant, Matthew Boulton, to gain support for his efforts.



Watt's steam engine was a great improvement over the Newcomen engine shown here.

In 1774, after moving to Boulton's manufacturing plant in Birmingham, Watt announced the successful trial of his steam engine. "The fire engine I have invented is now going and answers much better than any other that has yet been made," he said.

Watt continued to make improvements, using improved techniques in tool and metal making, so that his boiler could be made to precise measurements and withstand high pressure. Also, in Watt's engine, the back-and-forth movement of the piston was converted to circular motion. His engine was adopted by Robert Fulton for use in his river steamboat and by Richard Trevithick and George Stephenson in their steam locomotive. The steam engine was used to run machines in factories, especially the textile industry.

During the last years of his life, Watt continued to pursue his scientific interests. He formed the Birmingham Lunar Society. The Society met monthly—on the night of the full moon—so that members could travel home more safely by moonlight on roads that were usually dark. With his Lunar Society colleagues, Joseph Priestley, Erasmus Darwin, and Josiah Wedgwood, Watt discussed scientific phenomena and the study of nature for the good of everyone. Their group firmly believed in progress through the discovery and application of scientific principles.

CORBIS/MICHAEL LEWIS

Steam power is still used today. A train plows through a mountain pass in Colorado.

When James Watt died in 1819, he was recognized as having made significant contributions to science and to the world in his epitaph on a monument to his memory in Westminster Abbey:

James Watt…
…Enlarged the resources of his country,
increased the power of man, and
rose to an eminent place.
Among the most illustrious followers of
science and the real benefactors
of the world.… □

QUESTIONS

1. Why was the Newcomen engine inefficient?
2. How did Watt improve the Newcomen engine?
3. Name two people who used Watt's improved steam engine and tell how they used it.

Energy Star®: A Bright Idea

As part of a program called Energy Star®, the U.S. Environmental Protection Agency, the U.S. Department of Energy, and retailers, utilities, manufacturers, and state and local governments are helping Americans save energy, reduce costs, protect the environment, and enjoy the benefits of technology at the same time. These groups educate people about how to use energy efficiently. The companies manufacture energy-efficient products. Products that meet Energy Star® standards receive a special label.

The products approved by Energy Star® are big and small—they include highly energy-efficient refrigerators, lightbulbs, and just about everything in between. The government has given Energy Star® labels to qualifying computers, dishwashers, air conditioners, furnaces, and electric-powered doors.

Appliances and other devices that meet the U.S. Department of Energy's guidelines for energy efficiency display the Energy Star® label.

Take the lightbulb for starters. Did you know that only 10 percent of the electrical energy used by an incandescent lightbulb becomes light? The other 90 percent is wasted as heat. Halogen bulbs, which burn at temperatures up to 540 degrees Celsius, waste even more energy. A compact fluorescent bulb (CFL) that has earned the Energy Star® label uses 75 percent less energy than an incandescent bulb, but its light is every bit as bright. CFLs are more expensive than ordinary bulbs, but they last about 10 times longer.

For larger items, the possibilities for savings are

CORBIS/ROGER RESSMEYER

Energy-efficient fluorescent lightbulbs use less energy to produce light. The energy used by one incandescent bulb can light four fluorescent bulbs.

impressive. Refrigerators with the ENERGY STAR® label use 20 percent less electric power than other comparable models. The reason is better insulation and more precise temperature controls. ENERGY STAR®-approved washing machines use only half as much water as standard machines—for a savings of 7000 gallons of water per year in the average household. And when less water is used, there is less water to heat—a second source of energy savings.

Let's not forget the television set. Did you know that it uses energy even when it's turned off? The channel memory and remote control circuits can burn up to 12 watts of power, even when the screen is dark. An ENERGY STAR®-approved TV set, by contrast, uses just 3 watts of power when turned off. That's a 75 percent difference! Multiply that savings by the tens of millions of TVs in homes across America. You can see that ENERGY STAR® can make a difference.

The average American family could reduce its energy bills by about one-third if it bought ENERGY STAR®-rated products to replace existing ones. Office buildings, schools, and other structures can achieve savings as well.

When you go home tonight, you may want to look for the ENERGY STAR® labels on the appliances in your home. Or check out the labels in an appliance store in your area. How many things can you find with the ENERGY STAR® label? □

© MITCH KEZAR/PHOTOTAKE/PNI

Energy efficiency is not just about making efficient appliances. Insulating houses makes it easier to heat them in the winter and to cool them in the summer, which improves energy efficiency.