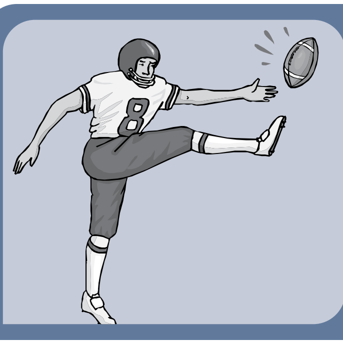

People Power

Students discover the difference between work and power by climbing stairs slowly and quickly and also learn to convert from one unit of power to another.

Grade Level: 5–8 (9–12)

Subject Areas: English Language Arts, Mathematics, Science

Setting: Classroom, Staircase

Time:
Preparation: 15 to 30 minutes
Activity: Two 50-minute class periods

Vocabulary: Electrical generator, Horsepower, Joule, Newton, Power, Turbine, Watt

Major Concept Area:

- Definition of energy

Objectives

Students will be able to:

- explain the difference between work and power; and
- convert from one unit of power to another.

Rationale

This activity allows students to use their own experience to explain the difference between work and power.

Materials

- Copies of ***Calculating Work and Power by Climbing Stairs***
- Bathroom scales (optional)
- Clipboards (optional)
- Rulers (yardsticks or meter sticks are optional)
- Stopwatch, digital watch, or watch with second hand
- Light bulb, preferably a 100-watt incandescent bulb (optional)

Background

When people say the words energy, work, or power in everyday conversations, listeners usually have little trouble understanding what these words mean. For example, one teacher might say to another, "I put a lot of work into my lesson plan last night, and it paid off. Today's class went really well." The other teacher would understand immediately what the first is talking about.

But what are the scientific definitions of energy, work, and power? Energy is often defined as the ability to do work. In turn, work has a specific definition in physics—it is equal to the force needed to move an object multiplied by the distance it is moved. Although the teacher planning the next day's lesson during the evening may say that he is doing work, by definition, work is done only when the teacher actually moves something, such as moving his pen to write his lesson plan.

To determine how much work a person does to move himself or herself, we need to measure the force exerted and the distance traveled. An easy way to do this is to have a student climb a flight of stairs. To climb the stairs, the student must do work to overcome gravity. The work done is equal to her weight, which is the force she must exert to overcome gravity, multiplied by the height of the staircase. For example, the work done by a student weighing 550 Newtons (N) and climbing a 3-meter-high staircase is:

Work = Force x Distance
= student's weight x height of staircase
= 550 Newtons x 3 meters
= 1,650 joules

NOTE: The Newton is the metric unit for weight, which is an object's mass (kg) times the acceleration due to gravity (9.8 m/s2. 550 Newtons is equal to about 125 pounds (1 lb. = .45 kg). To figure out your weight in Newtons using a bathroom scale, multiply the weight in pounds by .45 kg and then by the acceleration due to gravity (9.8 m/s2).

The joule (j) is the unit used to measure work. One joule of work requires that one Newton of force push an object a distance of one meter

work = force x distance

1 joule = 1 Newton x 1 meter.

The horizontal distance she traveled when going up the stairs is not counted since this distance is not in a direction that overcomes gravity.

Would the work done by a student slowly walking up the staircase be different than if she ran up the same staircase? No, because the definition of work does not take into account the time needed to climb the stairs (work equals force multiplied by distance). Yet the two situations are different. When the student runs up the stairs, she does the same amount of work in less time than when she walks up the stairs. In other words, she works faster. The term that expresses this difference is power, which is defined as the work done per unit of time, or the rate of doing work. In terms of a formula:

$$\text{Power} = \frac{\text{work done}}{\text{time}}$$

for stair climbing

$$\text{Power} = \frac{\text{weight (Newtons)} \times \text{height of stairs (meters)}}{\text{time (seconds)}}$$

The power output of the student walking up the stairs in 10 seconds is:

$$\text{Power} = \frac{\text{work done}}{\text{time}}$$

$$= \frac{550 \text{ N x } 3 \text{ m}}{10 \text{ seconds}}$$

$$= 165 \text{ watts}$$

The power output of the same student running up the stairs in two seconds is:

$$\text{Power} = \frac{550 \text{ N x } 3 \text{ m}}{2 \text{ seconds}}$$

$$= 825 \text{ watts}$$

One watt is equal to one joule of work done per second. Watts are a unit of power often associated with electrical equipment like light bulbs, hair dryers, and stereo amplifiers. Watts also describes the power output of engines and students running up stairs. The watt is a small unit of power. Therefore, multiples of the watt, such as the kilowatt (1,000 watts) or the megawatt (one million watts), are often used.

NOTE: In the United States, power for large motors such as in lawn mowers and automobiles is measured in an English unit called horsepower. One horsepower equals about three-quarters of a kilowatt. (See Watt's a Horsepower? for the origin of the unit of horsepower.)

Remember, power is the rate at which work is done. See the ***Power Data Table*** for sample power outputs.

In the stair climbing exercise, the student running up the stairs does 825 joules of work every second. At the end of two seconds, the time it takes the student to reach the top of the stairs, she will have done 1,650 joules of work.

Saying that a student expended four-fifths of a kilowatt of power running up the stairs sounds impressive. This is the same amount of power produced by more than eight 100-watt light bulbs. However, if the student's power output from running up the stairs could somehow be converted into electrical power, the bulbs would only stay on for two seconds.

Furthermore, a student cannot maintain a power output of four-fifths of a kilowatt by running up a staircase higher than 3 meters for more than a few seconds without growing tired and slowing down.

Running up stairs is not a practical way to produce electricity. Is there another way to convert a student's mechanical power into electrical power for light bulbs? The student could ride a stationary bicycle whose rear wheel is connected to a small electrical generator wired in a circuit to a light bulb. When the student pedals the bicycle, she generates electricity and lights the bulb.

In fact, generating electricity using a power plant is similar to generating electricity by riding a stationary bicycle. The boiler in a power plant converts the chemical energy in fossil fuels into the kinetic energy of steam by burning fossil fuels to boil water. This process is like a student's body converting the chemical energy from food into the mechanical energy of moving muscles. Like the rear wheel of the stationary bicycle, the turbine in a power plant is connected to an electrical generator. Heated steam pushing on the turbine blades spins the turbine, much like a student pushing on bicycle pedals spins the rear bicycle wheel. The mechanical energy of the spinning turbine or the spinning bicycle wheel is then converted into electrical energy by the generator. The electricity produced by the power plant generator travels through transmission lines to the lights in our homes. Similarly, the electricity produced by the generator connected to the bicycle wheel travels through the wires of a circuit to light a light bulb.

Finally, what about the teacher mentioned earlier who put a lot of work into his lesson plan? Does his brain's actual power output increase with extra mental effort? Studies that have measured the brain's power output showed that the difference between thinking hard and not doing so was about four watts—little more than the power output of a small candle burning to the end.

Procedure

Orientation

Ask students if a person does more work walking up a flight of stairs or running up the same flight of stairs.

Steps

1. Have students find a staircase, measure its height, and time how long it takes to walk up and run up the staircase. Students may try one of the following four approaches. NOTE: These approaches should be considered with respect to students who may be self-conscious about their weight or physical abilities.
   - Have students locate, measure, and climb a flight of stairs on their own time and bring their results to class.
   - Have one or two students walk up and run up the stairs while the rest of the class waits.
   - Provide students with a set amount of time with which to find a staircase in the school and conduct the measurements.
   - Walk up and run up a staircase yourself and provide students with the data.

   NOTE: The reason students are climbing stairs to measure the work they do is because their weight, which is equal to the force they need to overcome gravity, can easily be measured. Measuring the force they exert with their feet while walking across a floor is much more difficult (see **Background**).
2. Hand out and have students complete Parts I, II, and III of the activity sheet, ***Calculating Work and Power by Climbing Stairs***.
3. Discuss how students felt after climbing the stairs slowly compared to climbing them rapidly. If they did the same amount of work, why did they feel differently? They should note that the amount of time they used to climb the stairs was different. Explain to students that because it took less time to do work when running up the stairs, they expended more power.
4. Have students complete Part IV of the activity sheet. Discuss the different units of measurement for power. Relate them to different units of measuring length, such as meters and yards. Of the three units used to measure power, which have they heard of before?
5. Show students a 100-watt bulb. What do they think "100-watts" listed on the top of the bulb means? Explain that it refers to the power output of the bulb. A light bulb with a power output of 100 watts converts 100 joules of electrical energy into light and heat energy every second.
6. Ask where the energy to light the bulb comes from. Students may mention putting the bulb into a socket, flipping a switch, providing it with electricity, etc. Challenge students to explain how we get electricity. Briefly explain that one way to get electricity is to generate it in a power plant using fossil fuels (see **Background**).
7. Ask students if the power they expended by climbing the stairs could somehow be converted into electrical power. If so, could they produce enough electricity to light a light bulb?
8. Have students complete Part V of the activity sheet to determine how their power output from climbing the stairs relates to the power output of a 100-watt light bulb.
9. Ask students if it is possible to convert the power produced by a person into electrical power. Describe how this conversion can be done with a person riding a stationary bicycle with its rear wheel connected to an electrical generator. (A Pedal Power bicycle can be checked out from KEEP on keepprogram.org > Curriculum & Resources > Hands-on Resources.

You may also compare generating electricity using a bicycle with the way a power plant generates electricity (see **Background**).

Closure

Have students summarize their stair-climbing activity using the words work and power. Discuss what happened to the energy they used to climb the stairs.

Assessment

Formative

- Are students' activity sheets completed thoroughly and accurately?
- Are students able to explain the difference between work and power?
- Are students able to convert from one unit of power to another?
- Can students relate the power output of climbing stairs to other examples like engines and light bulbs?

Summative

- Have students give other personal examples that illustrate the difference between work and power.
- Have students calculate how much time it would take a person to climb stairs, if they know the height of the stairs, the weight of the person, and the amount of power produced. Example: The power output of a 240-pound (109 kg) football player running up a 25-foot (7.6 meters) high set of stairs in a stadium is equal to 1.5 horsepower (1,119 watts). How long did it take him to run up the stairs? (Answer: 7.2 seconds)

Extensions

Have the class do this activity using metric units for height, weight, work, and power. The class could also convert the units of energy used in this activity to other units such as Btus and calories.

Discuss the origin of the horsepower unit by having students read ***Watt's a Horsepower?*** After reading this, have students define a unit of their own such as the "studentpower," "humanpower," or "childpower," and then convert the horsepower figures from their ***Calculating Work and Power by Climbing Stairs*** activity sheets into the unit they have defined.

Challenge students to come up with ways to convert the mechanical energy of a person to other forms of energy.

Related KEEP Activities

Have students explore where they get their energy to conduct this activity through "Roasted Vittles." Additional information about generating electricity is found in "Diminishing Returns."

Power Conversion Chart

	watt (W)	kilowatt (kW)	megawatt (MW)	horsepower (hp)	foot-pounds/second (ft-lbs/sec)
1 watt =	1	0.001 kW	0.000001 MW	0.00134 hp	0.738 ft-lbs/sec
1 kilowatt =	1,000 W	1	0.001 MW	1.34 hp	738 ft-lbs/sec
1 megawatt =	1,000,000 W	1,000 kW	1	1,340 hp	738,000 ft-lbs/sec
1 horsepower =	746 W	0.746 kW	0.000746 MW	1	550 ft-lbs/sec
1 foot-pound/second =	1.36 W	0.00136 kW	0.00000136 MW	0.00182 hp	1

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Wisconsin K-12 Energy Education Program (KEEP)
College of Natural Resources
University of Wisconsin-Stevens Point

Watt's a Horsepower?

The origin of the term horsepower seems obvious: it is the power output of a horse doing work of some kind. But what exactly does this mean? How did the power of a horse come to be defined as precisely 550 foot-pounds per second?

When steam engines first appeared in England at the turn of the eighteenth century, they were used to pump water from mines, a task that horse-driven pumps had previously done. Soon, steam engines were rated in terms of the number of horses they could replace, or their "horsepower." For example, a steam engine might be rated at four horsepower, meaning that it could replace four horses. Rating steam engines this way gave people a general idea of a steam engine's power, but it was not a precise definition. How much power could horses actually produce? Were they big horses or small ones? What if the horses got tired after a while?

Attempting to answer these questions, a number of steam engine inventors and developers defined horsepower on their own. Some of these definitions even had specific values. For a time, however, no one could agree on a single definition for this unit, so few people took the horsepower rating of steam engines seriously.

By the late eighteenth century, James Watt (1736–1819) had made major improvements to the steam engine (he did not invent it). Because of his work, steam engines became more efficient and economical to use. Watt eventually became a successful businessman and by 1800, he and his partners had produced over 500 steam engines and his improvements were readily adapted by other manufacturers.

Watt understood that having different definitions of horsepower was confusing. How could customers compare steam engines made by different manufacturers, if different horsepower definitions were used? To end the confusion, Watt sought a definition of horsepower that everyone could agree with. He made a series of measurements to see how much weight an average horse could lift steadily. From this, Watt arrived at a figure of 550 foot-pounds per second. This value was eventually adopted and is now the accepted definition of one horsepower.

However, there is nothing special about this particular definition. A horsepower could easily have been defined as 500 foot-pounds per second. What must be remembered is that definitions of units are often chosen for convenience and are not necessarily related to the laws of science. People agree to use certain units because the definitions are sensible and because those who define the units are often in a position of influence in society. In the case of Watt, the success of his steam engines and his prominence as a scientist and businessman played as much a role in the adoption of his horsepower definition as did his measurements of a horse's ability to lift weights.

Not only did Watt define horsepower, his fame eventually led the scientific community to name a metric unit of power after him. Today, one watt is defined as one joule of energy per second, and one horsepower equals 746 watts.

Steam Engine

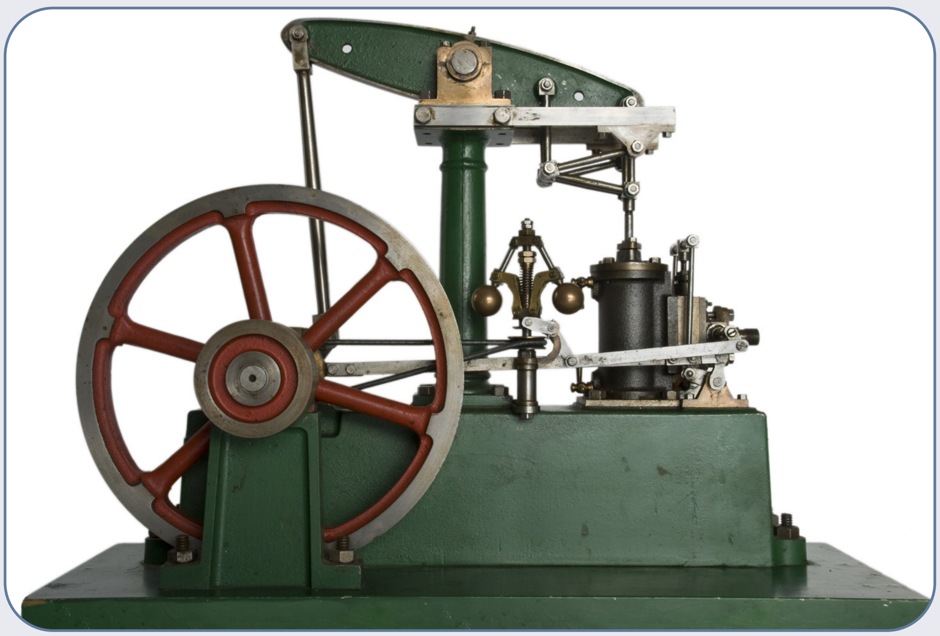

Photo credit: Baptist | Shutterstock

Power Data Table

	Horsepower	Watts
A hummingbird in flight	0.00094	0.7
A small candle burning to the end	0.004	3
Typical light bulbs used by homeowners Incandescent Compact Fluorescent (CFL) Light Emitting Diode (LED)	 0.034 to 0.402 0.05 to 0.4 0.012 to 0.044	 25 to 300 9 to 33 4 to 15
A gasoline-powered lawn mower	0.25 to 2	187 to 1,500
An adult human running a 100-meter dash in 10 seconds	1.74	1,300
A hair dryer	1.34 to 2	900 to 1,500
A horse Average (doing field work) Maximum (pulling a weight equal to 35 percent of horse's body weight)	 0.94 3	 700 2,240 (2.24 kW)
Watt's steam engines Typical range Largest engines	 10.7 to 21.4 134	8 to 16 kW 100 kW
Automobiles Typical 2017 models 2017 Smart Fortwo Prime 2017 Honda Accord	 66 to 640 89 185	 49 to 477 kW 66 kW 138 kW
The Columbia Power Plant in Portage, WI	3.5 million	1,000 MW
A moon rocket during launch (Apollo 11 on a Saturn C 5 rocket)	3.5 million	2,600 MW
The sun	5.1 x 1023	3.8 x 10^{26}

Adapted from "Table A2: Power Levels of Ephemeral Phenomena," p. 320 in Smil, Vaclav. General Energetics: Energy in the Biosphere and Civilization. New York: John Wiley and Sons, 1991. Used with permission.

Calculating Work and Power by Climbing Stairs

Introduction

In this activity, you will find out if a person does more work walking up a flight of stairs or running up the same flight of stairs by having you or someone else actually try this. You will also learn what scientists mean by the words work and power.

Part I

1. Find a staircase that is not used by a lot of people. Using a ruler, record the height of one step in centimeters in ***Table 1***.
2. Count the number of steps that you or your classmate will be climbing and record your answer in ***Table 1***.
3. Calculate the total height of the staircase in centimeters.
4. Calculate the total height of the staircase in meters.

Table 1	
1. Height of one step (cm)	
2. Number of steps climbed	
3. Total height of staircase (cm) = height of one step X number of steps climbed	
4. Total height of staircase (m) = total height of staircase (cm) / 100	

Part II

5. Next, decide who will be climbing the stairs and who will be recording the time of the stair climber. Write the name and the weight of the stair climber in the blank spaces below. If the stair climber does not know their weight, either use a scale and measure it, estimate the stair climber's weight, or use a standard weight of 100 pounds.

Name of stair climber	
Weight of stair climber (pounds)	

Calculating Work and Power by Climbing Stairs

6. To figure out weight in Newtons, multiply pounds by 0.45 kg and then by the acceleration due to gravity which is 9.8 meters/sec2.

   ________________ (lb) x .45 kg x 9.8 m/s^2 = ________________ Newtons

7. Have the stair climber climb the stairs slowly and steadily. Record the time it takes in seconds in ***Table 2*** under the column labeled "**Slowly**." You may want to practice this a few times to get an accurate time.

8. Now have the same stair climber climb the stairs rapidly. This does not mean that the stair climber has to risk getting hurt by climbing the stairs as fast as possible. Record the time it takes in seconds in ***Table 2*** under the column labeled "**Rapidly**." You may want to practice this a few times to get an accurate time.

   NOTE: It is important that the same stair climber climb the stairs slowly and rapidly because the same weight must be used to compare the work done while climbing the stairs for both cases.

Table 2

Climbing Stairs	Slowly	Rapidly
Time Required		

Part III

9. Calculate the work done by the stair climber in climbing the stairs slowly and rapidly using units of Joules. Record your answers in ***Table 3*** below.

   Formula: Work done (joules) = weight of stair climber (Newtons) x height of staircase (m)

Table 3

Climbing Stairs	Slowly	Rapidly
Work done (joules)		

10. Was the work done by climbing the stairs slowly the same as or different from climbing the stairs rapidly? Does your answer surprise you? Record your responses in the blank space below.

Calculating Work and Power by Climbing Stairs

Part IV

11. Calculate the power output of climbing the stairs slowly and rapidly in watts. Record your answers in ***Table 4*** below. The formula for calculating the power output in watts is:

Formula: $$\frac{\text{work done climbing stairs (joules)}}{\text{Time required to climb stairs (seconds)}}$$

Table 4		
Climbing Stairs	**Slowly**	**Rapidly**
Power output (watts)		

Part V

12. Suppose the power output of a person climbing stairs could somehow be directly converted into electrical power. How many 100-watt light bulbs could a person light by climbing the stairs slowly and rapidly? Record your answers in ***Table 5*** below. The formula for calculating the number of 100-watt light bulbs a student could light is:

Formula: $$\frac{\text{power output of student (watts)}}{\text{100 watts per bulb}}$$

Table 5		
Climbing Stairs	**Slowly**	**Rapidly**
Number of 100 watt light bulbs a person could light by climbing stairs		

Answer Key
Calculating Work and Power by Climbing Stairs

Introduction

In this activity, you will find out if a person does more work walking up a flight of stairs or running up the same flight of stairs by having you or someone else actually try this. You will also learn what scientists mean by the words work and power.

Part I

1. Find a staircase that is not used by a lot of people. Using a ruler, record the height of one step in centimeters in ***Table 1***.
2. Count the number of steps that you or your classmate will be climbing and record your answer in ***Table 1***.
3. Calculate the total height of the staircase in centimeters.
4. Calculate the total height of the staircase in meters.

Table 1	
1. Height of one step (cm)	**18 cm**
2. Number of steps climbed	**17 steps**
3. Total height of staircase (cm) = height of one step X number of steps climbed	**18 cm per step x 17 steps = 306 cm**
4. Total height of staircase (m) = total height of staircase (cm) / 100	**306 cm / 100 = 3.06 meters** **= 3 meters (rounded answer)**

Part II

5. Next, decide who will be climbing the stairs and who will be recording the time of the stair climber. Write the name and the weight of the stair climber in the blank spaces below. If the stair climber does not know their weight, either use a scale and measure it, estimate the stair climber's weight, or use a standard weight of 100 pounds.

Name of stair climber	**Jane Smith**
Weight of stair climber (pounds)	**125 pounds**

Answer Key
Calculating Work and Power by Climbing Stairs

6. To figure out weight in Newtons, multiply pounds by 0.45 kg and then by the acceleration due to gravity which is 9.8 meters/sec2.

   125 (lb) x .45 kg x 9.8 m/s^2 = **550** Newtons

7. Have the stair climber climb the stairs slowly and steadily. Record the time it takes in seconds in ***Table 2*** under the column labeled "**Slowly**." You may want to practice this a few times to get an accurate time.

8. Now have the same stair climber climb the stairs rapidly. This does not mean that the stair climber has to risk getting hurt by climbing the stairs as fast as possible. Record the time it takes in seconds in ***Table 2*** under the column labeled "**Rapidly**." You may want to practice this a few times to get an accurate time.

   NOTE: It is important that the same stair climber climb the stairs slowly and rapidly because the same weight must be used to compare the work done while climbing the stairs for both cases.

Table 2

Climbing Stairs	Slowly	Rapidly
Time Required	**10 seconds**	**2 seconds**

Part III

9. Calculate the work done by the stair climber in climbing the stairs slowly and rapidly using units of Joules. Record your answers in ***Table 3*** below.

   Formula: Work done (joules) = weight of stair climber (Newtons) x height of staircase (m)

Table 3

Climbing Stairs	Slowly	Rapidly
Work done (joules)	**550 Newtons x 3 meters = 1,650 joules**	**550 Newtons x 3 meters = 1,650 joules**

10. Was the work done by climbing the stairs slowly the same as or different from climbing the stairs rapidly? Does your answer surprise you? Record your responses in the blank space below.

    The same work was done when climbing the stairs slowly compared to climbing the stairs rapidly (= 1,650 Joules). This may seem surprising at first. However the formula for calculating the work done does not include the time it takes to climb the stairs – it only includes the weight of the student and the height of the stairs.

Answer Key
Calculating Work and Power by Climbing Stairs

Part IV

11. Calculate the power output of climbing the stairs slowly and rapidly in watts. Record your answers in ***Table 4*** below. The formula for calculating the power output in watts is:

Formula: $$\frac{\text{work done climbing stairs (joules)}}{\text{Time required to climb stairs (seconds)}}$$

Table 4

Climbing Stairs	Slowly	Rapidly
Power output (watts)	**1,650 joules / 10 seconds = 165 watts**	**1,650 joules / 2 seconds = 825 watts**

Part V

12. Suppose the power output of a person climbing stairs could somehow be directly converted into electrical power. How many 100-watt light bulbs could a person light by climbing the stairs slowly and rapidly? Record your answers in ***Table 5*** below. The formula for calculating the number of 100-watt light bulbs a student could light is:

Formula: $$\frac{\text{power output of student (watts)}}{\text{100 watts per bulb}}$$

Table 5

Climbing Stairs	Slowly	Rapidly
Number of 100 watt light bulbs a person could light by climbing stairs	**165 watts / 100 watts per bulb = 1.65 light bulbs**	**825 watts / 100 watts per bulb = 8.25 light bulbs**