Running the Stairs
Measuring Work, Energy, and Power

OBJECTIVE
Students will be timed while running up a flight of stairs, and will determine the work done against gravity and the power level at which they performed the work.

LEVEL
Middle grades: Physics

Middle Grades lessons are divided into Life, Earth, Chemistry and Physics subareas for ease of placement into any curriculum framework.

NATIONAL STANDARDS
UCP.3, B.4, B.5

CONNECTIONS TO AP
AP Physics:
II. Newtonian Mechanics, C. Work, energy, and power

All lessons support AP science topics.

TIME FRAME
45 minutes

MATERIALS
ruler or meter stick
string and plumb line
tape measure
bathroom scale
stopwatch

Teacher notes provide helpful classroom suggestions as well as connections to other concepts and LTF lessons.

TEACHER NOTES
In this activity, each student will measure his or her work done, potential energy, and power level as he or she climbs a flight of stairs. First, find a stairway that is at least one flight or higher, and open in such a way that you can measure its height with a string or long tape measure. Have each student stand on a bathroom scale and record his or her weight, then calculate his or her mass using the conversion on the datasheet. Take the students to the stairway, and choose a few students to measure the height of the stairs by tying a weight to the string, lowering it to the bottom, and measuring the length of the string from the bottom of the stairs to the top. Alternatively, you could give each student a centimeter ruler, and have them measure the height of each step, then multiply the average height of a step times the number of steps, or simply add the heights of all of the steps. Be sure and emphasize the use of the proper number of significant digits as discussed in *Foundation Lesson II: Numbers in Science*. Then, either stand at the top of the stairs with a stopwatch to time each student as he or she climbs the stairs, or assign a student to do so. After giving a student the signal to go, start the clock when his or her foot touches the first step. Tell the students they must touch each step as they climb. Tell each student his or her time, and have them perform the calculations on the data sheet and answer the conclusion questions.

POSSIBLE ANSWERS TO THE CONCLUSION QUESTION AND SAMPLE DATA

- Mass and weight conversion: 2.2 lbs. = 1 kg

$$100.\text{lbs.} \times \frac{1\,\text{kg}}{2.2\,\text{lbs.}} = 45.5\,\text{kg}$$

Sample student data and fully worked out student answers are provided.

- height of stairs *h* = <u>5.6</u> m
- time to climb stairs *t* = <u>6.7</u> s

SAMPLE CONCLUSION QUESTIONS

4. Brutus the football player has twice as much mass as you do, but takes twice as much time as you to run to the top of the stairs.
   a. Calculate Brutus's potential energy at the top of the stairs.
      - $PE = Work\ \ done = mgh = 2(45.5\,\text{kg})\left(9.8\frac{\text{m}}{\text{s}^2}\right)(5.6\,\text{m}) = 4994.0\,\text{J} = 5.0 \times 10^3\,\text{J}$ (2 sig. figs.)
   b. How does Brutus's power compare with yours? Justify your answer.
      - $P = \frac{W}{t} = \frac{4994.0\,\text{J}}{2(6.7\,\text{s})} = 372.7\,\text{watts} = 370\,\text{watts}$ (2 sig. figs.)

   Thus, Brutus operates at the same power level as the student, since he does twice the work in twice the time.

Conclusion questions ask students to apply concepts to new situations and to extend their thinking beyond the science laboratory.

5. A calorie (cal) is another unit of energy which is commonly associated with heat in the United States. A kilocalorie (Cal) is 1000 calories. The conversion between kilocalories and joules is 1.0 kilocalorie = 4184.0 J.
   a. How many kilocalories did you burn in climbing the stairs? Show your work.
      - $2500\,\text{J}\left(\frac{1\,\text{kilocalorie}}{4184.0\,\text{J}}\right) = 0.60$ kilocalories (2 sig. figs.)
   b. If you ate an energy bar consisting of 50.0 kilocalories, what percentage of the energy bar did you use to climb the stairs?
      - % of the energy bar used = $\frac{0.60\,\text{kilocalories}}{50.0\,\text{kilocalories}} \times 100 = 1.2\%$

T E A C H E R P A G E S

6. Discuss two reasonable sources of error in determining your power in climbing the stairs, and explain how each error increased or decreased your value for the power.
   - If the height of the stairs was measured higher than its actual value, the power would appear to be higher than it actually was. If the height was measured lower than its actual value, the power would appear to be lower than it actually was.
   - If the stopwatch was started too late, the power would appear to be higher than its actual value. If the stopwatch was started too early, the power would appear to be lower than its actual value.
   - If several steps were measured and an average step height was used to find the height of the stairway, the power may be higher if a large number of the steps were shorter than the average, or the power may be lower if a large number of the steps were taller than the average.

Students must justify their answers with data and supporting evidence to promote good technical writing skills.

TEACHER PAGES

Thorough introductions make connections across units of study and even courses.

Running the Stairs
Measuring Work, Energy, and Power

Any time *work* is done on an object the *energy* of that object is changed. When you climb stairs you do work on your mass and increase your potential energy. The amount of work you do is equal to the change in your potential energy. *Power* is the rate at which work is done. If you climb the stairs quickly, you operate at a high power level. If you climb the stairs slowly, your power level is low. Work and energy are measured in *joules* (J), and power is measured in *watts*.

The equation for the work done in lifting a mass from the ground level to a height h is

$$\text{Work} = mgh$$

where m is the mass of the object in kg, g is the acceleration due to gravity (9.8 m/s^2), and h is the height to which the mass is lifted.

The equation for power, P, is the work done divided by time t:

$$P = \frac{\text{Work}}{t}$$

PURPOSE

You will be timed while running up a flight of stairs, and will determine the work done against gravity and the power level at which you performed the work.

MATERIALS

- ruler or meter stick
- string and plumb line
- tape measure
- bathroom scale
- stopwatch

Safety Alert

1. Use caution when running up the stairs.
2. Do not skip any steps, but step on each one as you climb the stairs.
3. Be sure your shoestrings are securely tied.

Easy to follow student instructions

PROCEDURE

1. Stand on a bathroom scale to find your weight. Find the mass that corresponds to your weight by using the conversion given on your student answer page.

2. Find a stairway which has a vertical height of at least one floor.

3. Measure the height of the stairway in meters by attaching a weight to a string and lowering it from the top of the stairs to the bottom. Measure the length of the string with the tape measure or several meter sticks. Alternatively, measure the height of each step, and find the sum of the heights of all the steps. Record the height of the stairs in the appropriate space on your student answer page. When using a ruler, meter stick, or tape measure, remember to make your measurements to the correct number of significant digits and estimate between marks.

4. Have your teacher or a student stand at the top of the stairs with a stopwatch to measure the time it takes you to climb the stairs from the bottom to the top. Timing should begin the moment your foot touches the first step. Use caution while climbing the steps, and be sure to step on each step as you travel up the stairs.

5. Record the time it takes for you to run from the bottom of the stairs to the top in the appropriate space on your student answer page. Record your measurement to the correct number of significant digits.

Separate student answer pages allow teachers to minimize the number of copies required.

Name ______________________________________

Period ______________________________________

Running the Stairs
Measuring Work, Energy, and Power

DATA AND OBSERVATIONS

- Mass and weight conversion: 2.2 lbs. = 1 kilogram
- height of stairs h = ________________ m
- time to climb stairs t = _____________ s

ANALYSIS

Equations and constants: Remember to report the answers to all calculations to the proper number of significant figures.

$$\text{Work} = mgh$$

$$P = \frac{\text{Work}}{t}$$

$$g = 9.8\frac{m}{s^2}$$

1. In the space below, show your calculation for the work you performed on your mass against gravity as you climbed the stairs. Be sure to indicate the units for the work done.

2. In the space below, show your calculation for the power level at which you performed the work and indicate the units for power.

LAYING THE FOUNDATION
Building Academic Excellence

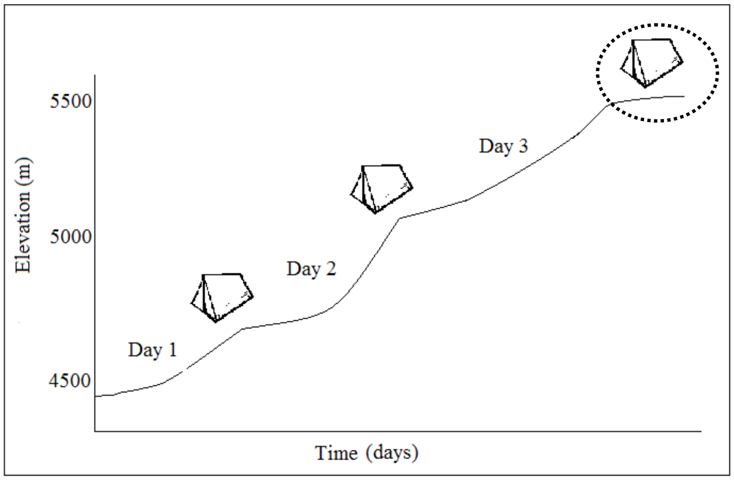
End of Course tests allow students the opportunity to take a cumulative AP style assessment and integrate concepts and learning from the entire course.

Excerpts from the 2006 6th Grade Free Response

Directions: The suggested time is about 15 minutes for answering a free response middle school question, which is worth 10 points. The parts within a question may not have equal weight. Show all your work in the spaces provided after each part. Pay particular attention to the proper use of significant digits and units.

Question 1 (10 pts)

A hiker went on a hike carrying a pack that weighs 200 N. The graph below represents the progress the hiker made during his three day hike. The tents represent his overnight stays.



Specific criteria for point accumulation aids teachers in consistently evaluating student papers.

A. On the graph above, circle the area where the potential energy of the hiker was the greatest. Justify your choice.

The hiker would have the greatest gravitational potential energy at Tent 3 since it is located at the highest elevation.	**1 point** circling Tent 3 or the plateau area at the highest portion of the graph. **1 point** for indicating that gravitational potential energy (or simply potential energy) increases as height or elevation increases

B. During which day did the hiker climb the fastest? Explain your answer.

Day 2 On Day 2 the slope of the graph is the steepest.	**1 point** for identifying Day 2 **1 point** for indicating the slope of this day's hike is the most vertical or steepest.

Questions apply skills that they learned in LTF lessons such as Running the Stairs.

C. How much work did the hiker do on his pack while carrying it from the base of the mountain to the top? Work = Force × Distance. Pay special attention to units when reporting your answer.

$200\ \text{N} \times 1000\ \text{m} = 200{,}000\ \text{N} \cdot \text{m}$ or Joules (a range of 180,000 to 220,000 J was accepted)	**1 point** for correct value **1 point** for correct units. (Unit point may be earned independent of value point)

D. Choose TWO of the energy types below and describe how energy is being transformed between them during the hike.

Students must synthesize information from different units of study and apply them to new situations.

- Chemical
- Mechanical
- Thermal

Chemical energy from the food the hiker ate is being transformed into the mechanical energy needed by the hiker in order to move up the mountain. Mechanical energy is turned into thermal energy as the hiker works to climb the hill and increases his body temperature or starts to sweat. Chemical energy stored in the fire wood is transformed into thermal energy to keep the hiker warm.	**2 point maximum** **2 points** for a correct description of an energy transformation. A maximum of **1 point** may be earned if students provide examples of 2 energy types relevant to the story but do not address the transformation of one energy type into the other.

Rollercoaster!
Measuring Energy and Force on a Rollercoaster

OBJECTIVE
Students will measure the potential energy at the top of a ramp, the kinetic energy at the bottom of the ramp, and the energy lost on the ramp. They will then use this value of kinetic energy to determine the maximum height of a loop that will allow a marble to successfully reach the end of the track. Students will also identify the forces acting on a rollercoaster car on the track.

As students progress from middle school to high school the format remains the same but the intensity and rigor increase as they get closer to the AP course.

LEVEL
Physics

NATIONAL STANDARDS
UCP.3, A.1, B.4

CONNECTIONS TO AP
I. Newtonian mechanics, B. Newton's laws of motion (including friction and centripetal force), C. Work, energy, power, 1. Work and work-energy theorem, 2. Conservative forces and potential energy, 3. Conservation of energy, E. Circular motion and rotation, 1. Uniform circular motion

TIME FRAME
Approximately 90 minutes

MATERIALS
(For a class of 28 working in groups of 4)

- 7 steel ball bearings, approx. ½" diameter
- 7 flexible molding tracks, each approximately 8 ft. long
- 7 meter sticks
- string and small weights to make a plumb-line
- tape measure
- 7 ring stands
- 7 clamps for clamping one end of each track to a ring stand
- 7 sheets of carbon paper
- 7 sheets of white paper
- masking tape

TEACHER PAGES

TEACHER PAGES

Teacher notes provide helpful classroom suggestions as well as connections to other concepts and activities

TEACHER NOTES

This activity combines the concepts of potential and kinetic energy, conservation of energy, energy loss due to friction and rotation, and circular motion. You can buy steel balls at a hardware store, and you'll need to make several tracks out of flexible molding. A good type of molding which can be fashioned into tracks is called White Cap, which can be purchased at Lowe's home improvement store or Home Depot in the doors and windows department. This type of molding is usually sold in 1½ inch widths and 8 foot lengths. You may wish to attach part of the molding track to 1"x 2" board for stability. The molding should be flexible enough to bend and curl into a loop, but rigid enough to hold its shape throughout the lab. Most likely, the students will have to hold the track during the lab to keep it in place while the steel ball rolls down the track.

You may want to precede this lab with a video on roller coasters, such as Nova's *Rollercoaster!* and have the students brainstorm the considerations rollercoaster engineers might need to include in designing a rollercoaster. You may choose to have the students think of a name and theme for their rollercoaster and present a poster advertising their rollercoaster.

POSSIBLE ANSWERS TO THE CONCLUSION QUESTIONS AND SAMPLE DATA

DATA AND OBSERVATIONS

PART I: TRACK CHARACTERISTICS

Mass m of your steel ball = 0.0060 kg

Length L of the track from the top of the ramp to the end of the track = 150.0 cm

Trial #	Initial height of ball above table h (m)	Distance from floor to bottom of ramp d_y(m)	Horizontal Distance d_x(m)
1	0.40	0.90	0.80
2	0.40	0.90	0.86
3	0.40	0.90	0.82

Excerpts from the Student Answer Page for Physics Lesson -- Rollercoaster!

Rollercoaster!
Measuring Energy and Force on a Rollercoaster

DATA AND OBSERVATIONS

PART I: TRACK CHARACTERISTICS

Mass m of your steel ball = _______________kg

Length L of the track from the top of the ramp to the end of the track = _____________ cm

Trial #	Initial height of ball above table h (m)	Distance from floor to bottom of ramp d_y (m)	Horizontal Distance d_x (m)
1			
2			
3			

ANALYSIS

PART I: TRACK CHARACTERISTICS

In Part I of the lab, we want to find the speed of the ball as it leaves the end of the ramp so that we can then find the kinetic energy at the end of the ramp. As the ball leaves the end of the ramp, it is moving horizontally and vertically at the same time. In the horizontal direction, it does not accelerate, but moves with a constant speed. In the vertical direction, the ball accelerates at 9.80 m/s^2 downward as it falls. We can combine the horizontal and vertical motions of the ball to find its speed, v, as it leaves the end of the track.

1. The time the ball is in the air after it leaves the end of the ramp can be found using the motion equation
   - $d_y = \frac{1}{2} g\mathbf{t}^2$

   where d_y is the vertical distance from the floor to the end of the ramp, and g is the acceleration due to gravity. Rearrange this equation for the time of flight **t** in terms of d_y and g. Show your steps in the space below.

4. Knowing the average horizontal distance d_x your steel ball traveled before striking the floor and the equation below, find the speed v of the ball in m/s as it leaves the track.

$$v = \frac{d_x}{t}$$

5. Using the equation for kinetic energy below, find the kinetic energy in Joules of the steel ball is it leaves the end of the track.

$$KE = \frac{1}{2}mv^2$$

6. Using the equation for potential energy below, find the potential energy in Joules of the steel ball when it is at the top of the ramp at the height h.

$$PE = mgh$$

7. According to the law of conservation of energy, the total energy of a system is neither created nor destroyed. The total energy of the ball at the top of the ramp (point A) is its potential energy, and the total energy of the ball at the end of the track (point B) is its kinetic energy.
   a. According to your calculations, is the potential energy of the ball at point A greater than, less than, or equal to its kinetic energy at the point B? Calculate any loss or gain in energy between points A and B.
   b. If the energy at point A is greater than at B, where did the energy go? If the energy at point B is greater than at A, where did it come from?

8. Using the equation below, find the percent of total energy lost or gained between points A and B.

$$\%\text{Energy lost} = \frac{\text{Energy at A} - \text{Energy at B}}{\text{Energy at A}} \times 100$$

9. Calculate the energy lost or gained per centimeter of track between points A and B.

$$\text{Energy lost or gained per centimeter} = \frac{\text{Energy lost or gained}}{L}$$

It should be noted that in the full version of the lab an accounting is made for the fact that much of the energy is in the form of rotational kinetic energy and is not actually "lost" due to friction.

12-14 diagnostic unit style tests consisting of multiple choice and free response questions are available for each science course.

LAYING THE FOUNDATION
Building Academic Excellence

PHYSICS
LTF® DIAGNOSTIC TEST
WORK, ENERGY, AND POWER

TEST CODE: 018030

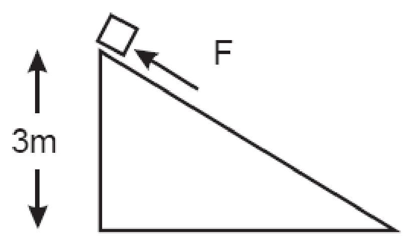
Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and fill in the corresponding oval on the answer sheet.

1. A 0.50-kg ball is dropped from a third- story window which is 20. m above the sidewalk. What is the speed of the ball just before it strikes the sidewalk?

A) 5.0 m/s
B) 10 m/s
C) 14 m/s
D) 20 m/s
E) 200 m/s

2.

Students are not permitted to use a calculator on the multiple choice questions. Questions are written with easy to manipulate values.



A 20.-kg cart is pushed up the inclined plane shown by a force **F** to a height of 3.0 m. What is the potential energy of the cart when it reaches the top of the inclined plane?

A) 150 J
B) 300 J
C) 600 J
D) 630 J
E) 1500 J

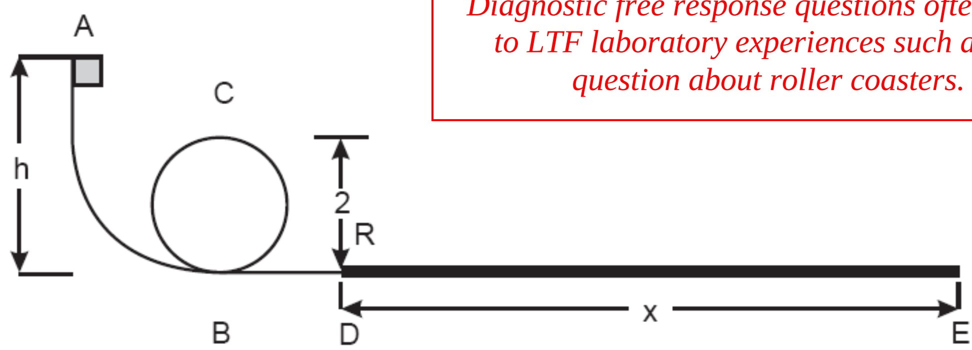
3. A tractor of mass 1000. kg pulls a plow of mass 150 kg across a field at a steady speed of 4.0 m/s by exerting a horizontal force of 5000. N. At what power level is the tractor doing work?

A) 4.1 kW
B) 8.0 kW
C) 12 kW
D) 20. kW
E) It is not possible to determine the answer without knowing the distance traveled

Directions: The suggested time is about 15 minutes for answering a free response physics question, which is worth 10 points. The parts within a question may not have equal weight. Show all your work in the spaces provided after each part. Pay particular attention to the proper use of significant digits and units.

Question 1 (10 pts)

Diagnostic free response questions often relate to LTF laboratory experiences such as this question about roller coasters.



A small block of mass *m* begins from rest at the top of a curved track at a height *h* and travels around a circular loop of radius *R*. There is negligible friction between the block and the track between points A and D, but the coefficient of kinetic friction on the horizontal surface between points D and E is μ. The distance between points D and E is *x*. Answer all of the following questions in terms of the given quantities and fundamental constants.

A. Determine the speed of the block at point B, at the bottom of the loop.

$U_A = K_B$ $mgh = \frac{1}{2}mv_B^{\ 2}$ Solving for v_B, $v_B = \sqrt{2gh}$	**1 point** For any statement of conservation of energy **1 point** For equating the potential energy at point A to the kinetic energy at point B **1 point** For the correct expression for velocity

B. Determine the kinetic energy of the block at point C, at the top of the loop.

$U_A = U_C + K_C$ $mgh = mg(2R) + K_C$ $K_C = mgh - 2mgR$	**1 point** For a correct statement of conservation of energy **1 point** For using the correct height at point C **1 point** For a correct expression for the kinetic energy at point C