Energy
Kinetic Energy, Potential Energy, and Work

CONCEPT EXPLORATION

In this unit you will be exploring the ideas of energy and work. At first we will concentrate on the concept of work and then investigate how this connects to the concept of energy.

The concept of energy is a relatively new idea compared to that of motion and forces. This may seem surprising since the use of energy and the pursuit of new sources of energy is so important to our society today. Do you have any energy?

Just what is work and how is it tied into the concept of energy will be our first topic for discussion.

Engagement Question

1. You are doing the most work when you:

A) hold a barbell in position at the end of you outstretched arms.
B) carry a barbell once around the running track.
C) lift a barbell over your head.
D) do any of the above. You are doing the same amount of work in each situation.

2. Explain why you selected the answer that you did for question 1.

In order for work to be done on an object, the object must move.

3. Which of the options presented in question 1 can be eliminated with this new information? Explain your answer.

The Challenge

You will be able to define the concept of work and you will be able to identify situations in which work is being done.

Your Ideas about the Challenge

4. In the table provided below draw and label the vectors on each diagram that represent the force that the woman is exerting on the sack of groceries and the direction of the displacement of the sack of groceries.

Scenario	Force vector	Direction of the displacement
A woman carries a sack of groceries into her kitchen.		

5. How does the direction of the force that the woman exerts on the sack of groceries compare to the direction of the displacement of the sack of groceries? Are they in the same direction?

6. In the table provided below draw and label the vectors on each diagram that represent the force that the woman is exerting on the sack of groceries and the direction of the displacement of the sack of groceries.

Scenario	Force vector	Direction of the displacement
The woman lifts the sack of groceries onto a high shelf.		

7. How does the direction of the force that the woman exerts on the sack of groceries compare to the direction of the displacement of the sack of groceries in this situation? Are they in the same direction?

8. Evaluate the following student statements about the amount of work that the woman did in the preceding situations. Indicate which student you agree with and which student you disagree with and why.

Student A
"I think that the woman did just as much work in each situation. She will get tired carrying groceries and she will get tired lifting the groceries."

Student B
"Getting tired is not a measure of how much work you have done on an object. I would get really tired just holding a sack of groceries in my arms and yet no work is done on the groceries unless you move them. I think that the force and the displacement need to be in the same direction in order for work to be done. When she lifted the sack of groceries she was working against the force of gravity."

Check your work with your teacher ☐

At each lab station you will find the following:
a bocce ball and a foam ball

The Investigation
a. Lift the foam ball a vertical distance of 1 meter. Set the foam ball down.
b. Lift the bocce ball a vertical distance of 1 meter. Set the bocce ball down.

9. Was it harder to lift the foam ball or the bocce ball? Why do you think that this was the case?

10. When do you think that you do the most work, when you lift a heavy object or when you lift a light object? Explain your answer.

The Investigation (continued)

a. Lift the bocce ball a vertical distance of 1 meter. Set the bocce ball down.
b. Lift the bocce ball a vertical distance of 2 meters. Set the bocce ball down.

11. When do you think that you do the most work, when you lifted the bocce ball to a height of 1 meter or when you lifted it to a height of 2 meters? Explain your answer.

12. Would lifting the bocce ball twice to a 1-meter height differ in the amount of work that you would do when you lift it just one time to a height of 2 meters? Explain your answer.

13. *What* does the work when you lower the bocce ball back down to the table top? Are you doing the work or is gravity doing the work? Explain your answer.

14. Evaluate the following student statements about the amount of work that you did in the preceding situations. Indicate which student you agree with and which student you disagree with and why.

<u>Student A</u>
"I'm only working when I lift an object up. This is because my force is in the same direction as the displacement on the way up. When I lower the object back down, the force of gravity is in the direction of the displacement. Gravity is doing all of the work on the way back down. Or, you could say that I am doing negative work as I lower an object, because my force is in the opposite direction of the displacement."

<u>Student B</u>
"If I slowly lower something I still get tired. I must still be doing work when I lower something to the ground."

Check your work with your teacher ☐

The Challenge

You will be able to describe how an object, that has been "worked" on, has the ability to do work on another object.

Your Ideas about the Challenge

You do work on a bocce ball by lifting it straight up into the air. You then hold it in place at its new position.
15. Does this bocce ball now have the ability to do work on another object? Explain your answer.

The Investigation (continued)

a. Use the bocce ball in two completely different ways to do some work on the foam ball.
b. Describe what you did in the table that follows and describe the kind of work that was done on the foam ball. You will need to mention the force and the displacement of the foam ball that occurs when the bocce ball was doing work on the foam ball.

	Description of how you used the bocce ball	Description of the work done on the foam ball
1		

2		

Check your work with your teacher

If an object has the ability to do work then it has **energy**. Energy can be defined as an objects ability to do work on another object or exert a force over a distance on another object.

16. Does the bocce ball have energy when you just simply hold it in place directly over the foam ball? Explain your answer.

When an object has energy due to its vertical position it is said to have **gravitational potential energy**. **Potential energy** is stored energy. There are many forms of potential energy.

17. Would the bocce ball have more or less gravitational potential energy if you held it at a greater height above the foam ball? Explain your answer.

18. Would the foam ball have as much gravitational potential energy as the bocce ball if you held it at the same height above another foam ball? Explain your answer.

19. Evaluate the following student statement about the investigation you performed and the questions that you just answered. Identify ideas that are consistent with your ideas and others that are not consistent with your ideas.

"A bocce ball held at a greater height, or a heavier ball, would have more gravitational potential energy that one held not so high or one that was not so heavy. This is because both the higher ball and the heavier ball have the ability to do more work."

Check your work with your teacher

20. Does the bocce ball have energy when you roll it along the table top directly towards the foam ball? Explain your answer.

A moving object has kinetic energy. **Kinetic energy** is the energy of motion.

21. Would a bocce ball have more kinetic energy if it was moving faster? Explain your answer.

22. Would a more massive ball, moving at the same speed, have more kinetic energy than the bocce ball? Explain your answer.

23. Evaluate the following student statement about the investigation you performed and the questions that you just answered. Identify ideas that are consistent with your ideas and others that are not consistent with your ideas.

"A faster moving ball and a more massive ball would have more kinetic energy than a slower ball and a lighter ball. This is because the faster or more massive ball has the ability to do more work."

Check your work with your teacher ☐

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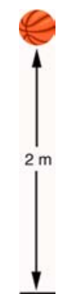
CONCEPT DEVELOPMENT

During the exploration activity you determined that an object has energy if it has the ability to do work. If an object is moving it has kinetic energy. The faster it moves the more kinetic energy it has. Also, a more massive object moving at the same speed as an object with less mass would have more kinetic energy than the object with less mass. Mass and velocity are a part of the kinetic energy expression. In this investigation you will discover the actual expression for kinetic energy.

An object is given gravitational potential energy if you do work on it by lifting it above its original position. You will find that the amount of gravitational potential energy that an object has is arbitrary. This development lesson will start by investigating gravitational potential energy.

Engagement Questions



A basketball is held at a position that is 2 meters above the floor.

1. Does this basketball have energy? Explain how you know.

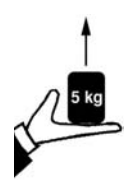
The Challenge

You will be able to calculate the amount of work that is done on an object as well as the amount of gravitational potential energy that the object gains. You will also know the unit breakdown for energy units.

Your Ideas about the Challenge

2. Calculate how much force you would have to exert on a 5 kg mass just to hold it in place. Explain how you know. Hint: draw the free-body diagram for the situation.

3. Calculate how much force you would have to exert on a 5 kg mass in order to lift it straight up at a constant speed. Explain how you know. Hint: draw the free-body diagram for the situation. Also, what is the acceleration of a mass if it is being lifted at a constant speed in a straight line?



If you exert a force on an object over a distance, you are doing **work** on that object. **Work** can be defined as the product of the force acting on a body and the distance over which this force is applied. A simplified version of the work equation is:

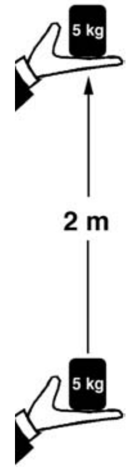
Work = Force · distance

or

$$W = F \cdot d$$

This form of the work equation is appropriate when the force, that is applied, is **constant** and is exactly in the **same direction** as the displacement of the object that the force acts upon.

4. Calculate how much work is done on a 5 kg mass that is lifted 2 meters straight up into the air at a constant speed. Be sure to show all of your calculations and carry through with the appropriate units.



The units that you should have received from your calculations should have been $\mathrm{kg} \cdot \frac{\mathrm{m}}{\mathrm{s}^2} \cdot \mathrm{m} = \mathrm{N} \cdot \mathrm{m}$. A Newton times a meter (N · m) is called a joule in honor of James Joule who experimented with heat and other forms of energy in the 19th century. One joule (J) is equal to the force of one Newton applied over a distance of 1 meter. Therefore 98 N· m is 98 J.

Check your work with your teacher.

The work done in lifting a 5 kg mass to a height of 2 meters at constant speed, gives the mass gravitational potential energy. The amount of gravitational potential energy that the mass acquired is equal to the amount of work that was done on the mass. The mathematical expression for gravitational potential energy (PE) can be derived from our simplified version of the work equation. The force exerted on the mass is equal to the weight of the mass (mg) and the vertical distance that the mass is lifted is referred to as the height (h).

$$\mathbf{W = F \cdot d}$$
$$\downarrow \quad \downarrow \quad \downarrow$$
$$\mathbf{PE = mg \cdot h}$$

5. Calculate the amount of gravitational potential energy that the 5 kg mass acquired as it was lifted 2 meters straight up into the air at a constant speed.

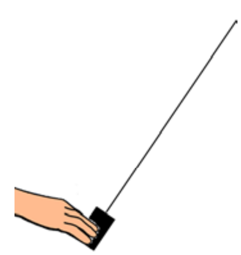
6. What units did you receive for the gravitational potential energy in question 5? How do these units differ from the units for the work that was done on the 5 kg mass in question 4?

The Challenge

You will be able to confirm that an object with gravitational potential energy has the ability to do work.

Your Ideas about the Challenge

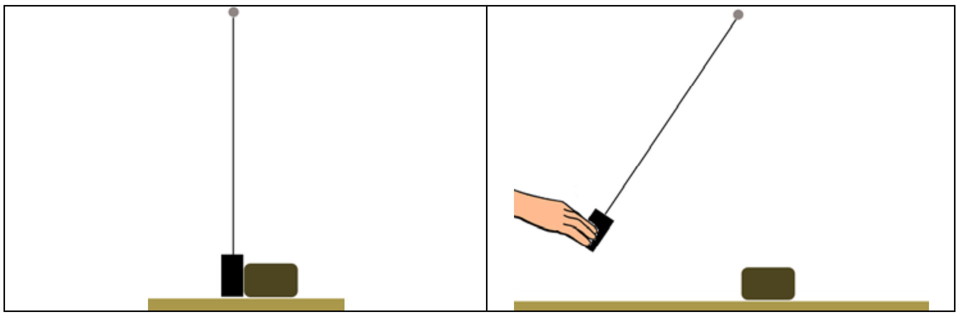
7. Does a mass at the end of a string, displaced from its equilibrium position, have gravitational potential energy? Explain your answer.



At each lab station you will find the following:
a pendulum arrangement, a box with mass equal to the mass at the end of the string, two meter sticks.

The Investigation

a. While the mass hangs at rest at the end of the string, place the box right next to the mass on the table top.
b. Pull the pendulum mass back from the box so that the center of this mass is 5 cm above the table top.
c. Release the mass so that it strikes the box. The mass should come to rest after impact.
d. Measure (in cm) the distance that the box slides on the table top. Record this distance in the data table that follows.
e. Repeat steps “a” through “d” four more times.
f. Repeat steps “a” through “e” after raising the mass to a height of 10 cm above the table top.
g. Calculate the average of the sliding distances for both the 5 cm release height and the 10 cm release height.



Data Table

Trial	5 cm height sliding distance (cm)	10 cm height sliding distance (cm)
1		
2		
3		
4		
5		
Average		

8. How much more gravitational potential energy did the mass at the end of the string have when it was raised to the 10 cm height compared to the 5 cm height? Was it twice as much?

9. Did the mass at the end of the string do work on the box when it hit the box? Explain your answer.

10. What kind of energy did the box acquire as a result of the impact with the mass? Explain your answer.

11. What force made the box *stop* sliding on the table top? Did this force do any work in bringing the box to a stop? Explain your answer.

12. How much farther did the box slide when the mass was raised to the 10 cm height compared to the 5 cm height? Was it roughly twice as far? If it not, what do you think happened?

13. Evaluate the following student statements. Determine which statement you agree with and which statement that you disagree with and why.

<u>Student A</u>

"The pendulum mass didn't gain twice as much gravitational potential energy when I pulled it back to the 10-cm position. I didn't have to pull it as far to get it another 5 cm above the table top as I did when I first got it to the 5-cm position. That's why the box didn't slide twice as far. We should have measured along the arc path that the pendulum followed rather than above the table top."

<u>Student B</u>

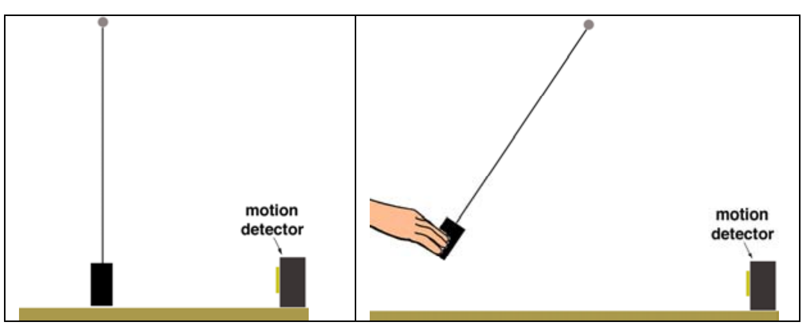
"Bullfeathers! The height that you use to determine gravitational potential energy has to be a vertical distance. The box didn't slide twice as far because it lost energy to heat and sound."

Check your work with your teacher. ☐

At each lab station you should find the following materials:
a motion detector with a computer and interface, a pendulum arrangement, a box with mass equal to the mass at the end of the string, and two meter sticks

The Investigation (continued)

a. Place the motion detector on the table top so that it will read the velocity of the pendulum mass at its lowest position. You should have a velocity time graph on your computer display.
b. Pull the mass at the end of the string back so that its center of mass is 5 cm above the table top.
c. Start the computer program.
d. Release the mass so that it swings down and towards the motion detector. Read the maximum velocity achieved by the pendulum mass. Repeat this procedure to make sure you are getting about the same maximum-velocity value each time.
e. Repeat steps "b" through "d" for the mass pulled back to successively greater heights. Determine how high the mass must be in order to double the maximum velocity that you received at the 5-cm position. Record this height in the date table that follows.



Data Table

Doubled-velocity position (cm)	

14. Did you double the height to get twice the velocity at the bottom position? If not, what do you think happened?

15. If the mass is moving twice as fast, do you think that it would have twice as much kinetic energy?

The Investigation (continued)

a. Remove the motion detector and position the box so that it rests up against the pendulum mass, at rest, as you had done earlier.
b. Pull the pendulum mass back from the box so that the center of this mass is 5 cm above the table top.
c. Release the mass so that it strikes the box. The mass should come to rest after impact.
d. Measure (in cm) the distance that the box slides on the table top. Record this distance in the data table that follows.
e. Repeat steps “a” through “d” four more times.
f. Repeat steps “a” through “e” after raising the mass to the doubled-velocity position above the table top.
g. Calculate the average of the sliding distances for both the 5 cm release height and the doubled-velocity release height.

Data Table

Trial	10-cm position sliding distance (cm)	Doubled-velocity position sliding distance (cm)
1		
2		
3		
4		
5		
Average		

16. Did the box slide roughly twice as far when the pendulum mass was going twice as fast? If not, what do you think happened?

17. Are you doing work on a baseball if you throw it? Explain your answer.

18. What kind of energy does the baseball acquire if you throw it?

The theoretical amount that it increases can be seen from the following derivation for the kinetic energy expression.

Kinetic Energy Derivation

Work is equal to force times distance.	$W = F \cdot d$
From Newton's 2nd law it can be seen that force is equal to mass times acceleration.	$F = ma$
Substitute the expression, mass times acceleration, in for force in the work equation.	$W = ma \cdot d$
Solve the kinematics equation $v^2 = v_0^2 + 2ad$ for acceleration times distance (ad).	$ad = \frac{v^2 - v_0^2}{2}$
If the initial velocity is zero then the expression above can be reduced.	$ad = \frac{v^2}{2}$
Substitute the value for acceleration times distance into the work equation $W = m \cdot ad$.	$W = m \cdot \frac{v^2}{2} = \frac{1}{2}mv^2$

When an unbalanced or net force is applied to an object, the object will accelerate ($F_{net} = ma$). If the acceleration results in a change in speed, there will be a change in the amount of kinetic energy of the object. The work done on the object is equal to the kinetic energy acquired by the object.

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

19. You throw a 0.25 kg baseball so that it acquires a speed of 10 m/s. Calculate the amount of kinetic energy that you gave to this baseball. Be sure to label all of your quantities and the answer with the appropriate units.

20. How do the units that you received for the amount of kinetic energy acquired by your baseball compare to the units that we use for work and gravitational potential energy?

21. Calculate the amount of kinetic energy that the baseball (mentioned in question 19) would have if you gave it a speed of 20 m/s.

22. By how much did the kinetic energy of the baseball change when you doubled the speed? Did the amount of kinetic energy double? Why do you think that this happened?

Check your work with your teacher. ☐

Energy
Kinetic Energy, Potential Energy, and Work

CONCEPT REFINEMENT

Review

If you apply a force over a distance on an object you are doing work on that object.

$$W = F \cdot d$$

If you do work on an object you give that object energy.

You now know about two kinds of energy. One of these is the energy of motion known as kinetic energy. If an object is moving, it has kinetic energy. The mathematical expression for kinetic energy is:

$$KE = 1/2mv^2$$

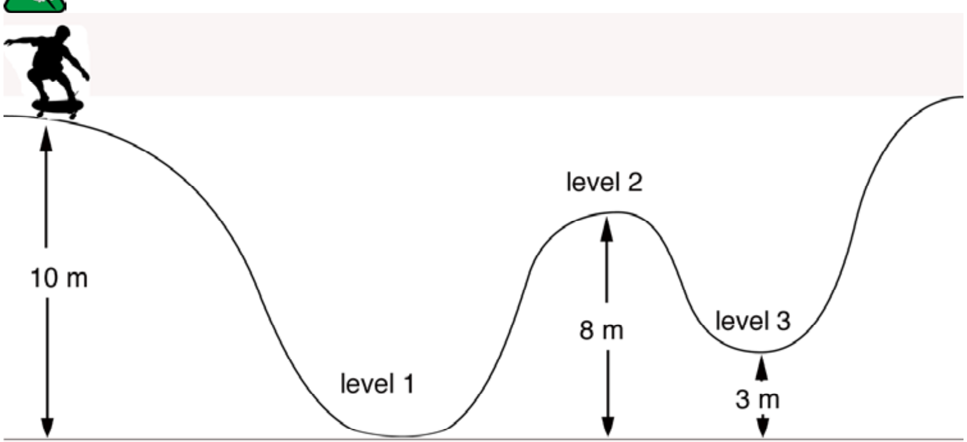
The other kind of energy that you were introduced to was gravitational potential energy. The mathematical expression for gravitational potential energy is:

$$PE = mgh$$

Whether an object has any gravitational potential energy or not, is up to you. The amount of gravitational potential energy that an object has depends on the vertical location of a reference or base level. You get to choose where this base or reference level is.

Shown below is a 60 kg skateboarder at the top of a hill.

1. Calculate the amount of gravitational potential energy that the skateboarder has at the top of the first hill with respect to each of the three levels labeled in the diagram.



Level	**Gravitational potential energy**
1	
2	
3	

Check your work with your teacher.

A 3 kg bowling ball is thrown straight up into the air so that it rises to a height of 8 meters above the position from which it was released.

2. As measured with respect to the original release point of this bowling ball, calculate how much gravitational potential energy the bowling ball has as it reaches each of the indicated points on the way up.

Height (h)	PE
0	
2 m	
4 m	
6 m	
8 m	

3. What kind of energy did the bowling ball, shown in the previous problem, have at the moment of release as it first began to rise and before it had gained any gravitational potential energy? Explain how you know this.

4. How much kinetic energy did this bowling ball have at the highest point before it started to fall back down? Explain how you know.

Check your work with your teacher.

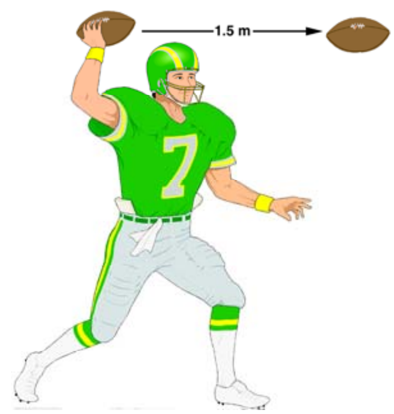
	Bowling ball level	Calculated velocity	Calculated kinetic energy
Another 3 kg bowling ball is dropped from a height of 8 meters. **5. Fill out the table provided by calculating both the velocity and the amount of kinetic energy that this bowling ball has as it falls.** **Use the equation $v^2 = v_0^2 + 2ad$ to calculate the velocity. Be sure to show all of your work.**			

6. What kind of energy did this bowling ball have when it was first released from rest and had just begun to fall? Explain how you know.

7. How much gravitational potential energy did this bowling ball have when it hit the ground? Explain your answer.

Check your work with your teacher.

You exert a force of 10 N over a distance of 1.5 meters as you throw a football.



8. How much work do you do on this football?

9. How much kinetic energy does this football acquire after you release it? Explain how you know this.

10. If the football has a mass of 0.5 kg, how fast is it moving when you release it?

Check your work with your teacher.