SCOPE, SEQUENCE, and COORDINATION

A National Curriculum Project for High School Science Education

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SCOPE, SEQUENCE, and COORDINATION

Teacher Materials

Learning Sequence Item:

935

Work and Energy

March 1996
Adapted by: Arthur Eisenkraft

National Science Education Standard—Physical Science

Conservation of Energy and the Increase in Disorder

The total energy of the universe is constant. Energy can be transferred by collisions in chemical or nuclear reactions, by light waves and other radiations, and in many other ways. However, it can never be created or destroyed. As these transfer occur, the matter involved becomes steadily less ordered.

All energy can be considered either kinetic energy, which is the energy of motion; potential energy, which depends on relative position; or energy contained by a field, such as electromagnetic waves.

Motions and Forces

When a force acting on an object has the effect of producing a rotation, the resulting angular motion often can be attributed to a quantity called torque, and the laws of that motion are somewhat analogous to Newton's laws for translational motion. (The analogy is not exact or general, since the rotational inertia, I, is, in general, a tensor, whereas mass, m in Newton's law, is a scalar; thus, the two relationships cannot be exact analogs.) When more than one torque acts on an object and they sum to zero, the system is said to be in rotational equilibrium.

Work, Kinetic Energy, Potential Energy, Field Energy, and the Conservation of Energy. (a) Students learn the definition of work, in joules, as force times the distance the object moves in the direction of the force. They should learn that the effect of a net force on an object is to increase its speed, and that the work done on the object by that force results only in an observable change in speed. Thus the work done produces an energy of motion we call kinetic energy. Work should be calculated only in situations where the force and displacement are along the same line and in the same direction. *(Physics, A Framework for High School Science Education, p. 28.)*

Rotational Dynamics and Angular Momentum. (b) At this level, students should learn the basic concepts of a fulcrum and lever. *(Physics, A Framework for High School Science Education, p. 16.)*

Contents

This micro-unit was adapted by **Arthur Eisenkraft** (Fox Lane H.S., Bedford, N.Y.)

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Learning Sequence

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Rotational Dynamics and Angular Momentum. (b) At this level, students should learn the basic concepts of a fulcrum and lever. *(Physics, A Framework for High School Science Education, p. 16.)*

Science as Inquiry	Science and Technology	Science in Personal and Social Perspectives	History and Nature of Science
A Moving Experience Activity 1	Designing Vehicles Assessment 12	Energy Sources Assessment 15	Work and Kinetic Energy Assessment 4
Move It! Activity 2			
Give Me A Brake! Activity 3			
Work and the Wall Assessment 1			
Pat's Job Assessment 2			
Falling Leaf & Work Assessment 3			
Work and Kinetic Energy Assessment 4			
Mass & Speed Assessment 5			
Speed & Kinetic Energy Assessment 6			
Falling Freely Assessment 7			
Dropping the Ball Assessment 8			
Work Force Assessment 9			
Jack Force Assessment 10			
Acceleration Assessment 11			
No Work? Assessment 13			
Battering Ram Assessment 14			
Match This! Assessment 16			
Duelling Skateboards Assessment 17			
Force & Mass Assessment 18			

Suggested Sequence of Events

Event # 1

Lab Activity

1. A Moving Experience (30 minutes)

Alternative or Additional Experiments

2. Move It! (30 minutes)
3. Give Me A Brake! (30 minutes)

Event #4

Readings from Inquiry, Science and Technology, Personal and Social Perspectives, and History of Science

Suggested Readings:

Doherty, Paul, “Homework Assignment #3,” *Exploring: Puzzles & Problems,* The Exploratorium, Vol. 17, No. 2, Summer 1993, pp. 9–11, 34.

Doherty, Paul, “The Physics in Your Toolbox,” *Exploring: Tools,* The Exploratorium, Vol. 17, No. 1, Spring 1993, pp. 8–13.

Assessment Recommendations

This teacher materials packet contains a few items suggested for classroom assessment. Often, three types of items are included. Some have been tested and reviewed, but not all.

1. Multiple choice questions accompanied by short essays, called justification, that allow teachers to find out if students really understand their selections on the multiple choice.

2. Open-ended questions asking for essay responses.

3. Suggestions for performance tasks, usually including laboratory work, questions to be answered, data to be graphed and processed, and inferences to be made. Some tasks include proposals for student design of such tasks. These may sometimes closely resemble a good laboratory task, since the best types of laboratories are assessing student skills and performance at all times. Special assessment tasks will not be needed if measures such as questions, tabulations, graphs, calculations, etc., are incorporated into regular lab activities.

Teachers are encouraged to make changes in these items to suit their own classroom situations and to develop further items of their own, hopefully finding inspiration in the models we have provided. We hope you may consider adding your best items to our pool. We also will be very pleased to hear of proposed revisions to our items when you think they are needed.

Science as Inquiry

A Moving Experience

How does force and distance relate to kinetic energy?

Overview:

In this activity students will use cars and bathroom scales to examine the relationship between force, distance and kinetic energy.

Materials:

Per lab group:
automobiles (of different mass), 2
bathroom scales, 2
ticker-tape timers
ticker tape
meter stick (or tape measure)
masking tape

Procedure:

Meet the students in the school parking lot. Position one car (of smaller mass) so that there is at least 30 meters of level ground for the car to travel upon. Use the masking tape to attach the ticker tape to the rear of the car. Have two students push the car by pressing on the bathroom scales (positioned at the back of the car). Instruct the students to push as hard as they can and to continue to push, using the same level of pressure or force, after the car begins to move. The ticker tape will record the motion of the car. Students should create a data table and record the force registered on the bathroom scale; the total distance the car moved; the final velocity of the car (computed from the ticker tape); and the mass of the car as given in the manual (or on the driver registration). Have them repeat the experiment, using less force to move the car, and record these results. Finally, have students repeat the experiment using the second, more massive car, and record these results.

Students should compare the work (force ∞ distance) with the increase in kinetic energy of the car ($^1/_2mv^2$). Qualitatively, students should recognize that changes in force or distance provide changes in kinetic energy.

Background:

This is a group activity that provides a large scale demonstration of the relationship between force, distance and kinetic energy (work = change in kinetic energy). Work is defined as a force exerted over a certain displacement ($W = Fd$). The force and the displacement must be in the same direction or only a component of the force should be used in the calculation. We will use examples where they are in the same direction. Kinetic energy is defined as $^1/_2mv^2$.

The definitions of these terms should be left to the end of the activity. Students should focus on how changes in the force, or distance that the force is exerted upon, change the motion (velocity) of the car; and how changes in the mass of the car change the motion of the car.

The ticker-tape timer records a dot every $^1/_{40}$ of a second. The final velocity of the car an be calculated by measuring the distance d for the final 10 ticks. The velocity is the change in distance divided by the change in time. If we assume that the last 10 ticks are 0.30 meters, the velocity can be calculated:

$v = d/t = 0.30$ meters/($^{10}/_{60}$ s) = 1.8 m/s

Knowing this final velocity and multiplying by the mass of the car will be students one quantity.

The qualitative understanding of the students should reveal that to get the car to move faster, they can increase the force or increase the distance that the force is acting. This leads to a "guess" that the force multiplied by the distance may be an important number. The students should measure the total length of the ticker tape to determine the total distance that the car traveled. The force exerted is the sum of the forces of the two sales. It is useful to convert and record these forces as Newtons so that the entire calculation can be completed in SI.

The students can then compare the mass ∞ velocity calculation with the force ∞ distance calculation. They will find that there is not a numerical relationship. However, if they try to calculate $^1/_2mv^2$, they will note that this quantity is almost equal to the force ∞ distance calculation.

The calculation can be repeated for the second set of students on the second car. The four sets of data should convince the students that force ∞ distance and $^1/_2mv^2$ are important quantities in this problem. At this point, it is worth stating that each of these has a "name":

force ∞ distance is defined as work
$^1/_2$ mass ∞ velocity^2 is defined as kinetic energy.

Variations:

None.

Adapted from:
Unknown.

an alternative activity for Event 1

Teacher Sheet

Science as Inquiry

Move It!

What is the relationship between work, force and kinetic energy?

Overview:

This activity focuses on work, force and kinetic energy. The cart's mass is varied and distance and time is measured.

Materials:

Per lab group:

lab cart
bricks (or books)
hanging masses
pulley
ticker tape timer (or sonic ranger)
string
balance (to measure masses)
spring scale (to measure weight)

Procedure:

Students will set up the lab cart so that it is pulled by the smaller mass that is hanging over the table. They should record the force of the pulling weight; the mass of the cart (plus bricks); the distance the cart moves; and the final velocity of the cart. The force of the pulling weight is determined by hanging the mass from a Newton spring scale. The mass of the cart (plus bricks) is measured with a triple beam balance. They can measure the distance the cart travels with a meter stick and the final velocity of the cart with a ticker tape timer or sonic ranger.

Students should vary the hanging mass; the mass of the pulled cart; and the distance the cart travels.

Background:

This is a small group activity that provides an analysis of the relationship between force, distance and kinetic energy (work = change in kinetic energy). Work is defined as a force exerted over a certain displacement (W = Fd). The force and the displacement must be in the same direction or only a component of the force should be used in the calculation. We will use examples where they are in the same direction. Kinetic energy is defined as $\frac{1}{2}mv^2$.

The definitions of these terms should be left to the end of the activity. The students should be focused on how changes in the force, or distance that the force is exerted, change the motion (velocity) of the cart, and how changes in the mass of the cart changes the motion of the cart.

The ticker tape timer records a dot every $\frac{1}{40}$ of a second. The final velocity of the cart can be calculated by measuring the distance d for the final 10 ticks. The velocity is the change in distance divided by the change in time. If we assume that the last 10 ticks are 0.10 meters, the velocity can be calculated:

$v = d/t = 0.10 \text{ meters}/({}^{10}/_{60}\ s) = 0.6 \text{ m/s}$

Knowing this final velocity and multiplying by the mass of the cart will give the students one quantity.

The qualitative understanding of the students should reveal that to get the cart to move faster, they can increase the force (the falling weights) or increase the distance that the force is acting. This leads to a “guess” that the force is multiplied by the distance may be an important number. The students should measure the total length of the ticker tape to determine the total distance that the cart traveled. The force exerted is the sum of the forces of the two scales. It is useful to convert and record these forces as Newtons so that the entire calculation can be completed in SI.

The students can then compare the mass ∞ velocity calculation with the force ∞ distance calculation. They will find that there is not a numerical relationship. However, if they try to calculate ${}^{1}/_{2}mv^2$, they will note that this quantity is almost equal to the force ∞ distance calculation.

The calculation can be repeated for the second set of students and the second cart. The four sets of data should convince the students that force ∞ distance and ${}^{1}/_{2}mv^2$ are important quantities in this problem. At this point, it is worth stating that each of these has a “name”:

force ∞ distance is defined as work
${}^{1}/_{2}$ mass ∞ velocity^2 is defined as kinetic energy.

Note: The falling mass must be much less than the mass of the cart (and bricks) for the experiment to be valid.

Variations:

None.

Adapted from:
Unknown.

an alternative activity for Event 1

Teacher Sheet

Science as Inquiry

Give Me A Brake!

What is the relationship between work, force and kinetic energy?

Overview:

This activity focuses on work, force and kinetic energy. The cart's mass is varied and distance and time is measured.

Materials:

Per lab group:
lab cart
bricks (or books)
ramp
meter sticks
ticker tape timer (sonic ranger or photogates)
spring scale (to measure weight)

Procedure:

The force of friction is determined by pulling the cart on level ground with a Newton spring scale. Students will begin the activity by determining the force of friction of the cart on the floor. This can be accomplished by measuring the force required to keep the cart moving at a constant velocity. The students will pull the cart with a spring scale at a constant speed. They should note that a larger force will produce an increase in the speed of the cart—and that with a smaller force, the cart is not able to maintain the speed. The reading of the spring scale is equal to the force of friction.

Students will then roll the cart down a ramp and let it come to rest on the floor. During several trials, they need to record the mass of the cart (plus bricks), the distance the cart moves, and the velocity of the cart at the bottom of the ramp. The mass of the cart (plus bricks) is measured with a triple beam balance. They measure the distance the cart travels with a meter stick, and the velocity of the cart at the bottom of the ramp with a ticker tape timer, sonic ranger or photogate.

Students should vary the mass of the cart; the steepness of the ramp or the distance the cart travels down the hill; and the friction by "freezing-up" the wheels.

They will compare the work (force ∞ distance) with the increase in kinetic energy of the cart ($^1/_2 mv^2$). Qualitatively, the students should recognize that changes in force or distance provide changes in kinetic energy.

Background:

This is a small group activity that provides an analysis of the relationship between force, distance and kinetic energy (work = change in kinetic energy). Work is defined as a force exerted over a certain displacement (W = Fd). The force and the displacement must be in the same direction or only a component of the force should be used in the calculation. We will use examples where they are in the same direction. Kinetic energy is defined as $^1/_2 mv^2$.

The definitions of these terms should be left to the end of the activity. The students should be focused on how changes in the force, or distance that the force is exerted, change the motion (velocity) of the cart, and how changes in the mass of the cart changes the motion of the cart.

The ticker tape timer records a dot every $^1/_{40}$ of a second. The final velocity of the cart can be calculated by measuring the distance d for the final 10 ticks. The velocity is the change in distance divided by the change in time. If we assume that the last 10 ticks are 0.10 meters, the velocity can be calculated:

$$v = d/t = 0.10 \text{ meters}/(^{10}/_{60} \text{ s}) = 0.6 \text{ m/s}$$

Knowing this final velocity and multiplying by the mass of the cart will give the students one quantity.

The qualitative understanding of the students should reveal that to get the cart to travel farther, they can increase the speed of the cart or decrease the friction of the cart. This leads to a “guess” that the force is multiplied by the distance may be an important number. The students should measure the total length of the ticker tape to determine the total distance that the cart traveled. The force exerted is the sum of the forces of the two scales. It is useful to convert and record these forces as Newtons so that the entire calculation can be completed in SI.

The students can then compare the mass ∞ velocity calculation with the force x distance calculation. They will find that there is not a numerical relationship. However, if they try to calculate $^1/_2mv^2$, they will note that this quantity is almost equal to the force ∞ distance calculation.

The calculation can be repeated for the second set of students and the second cart. The four sets of data should convince the students that force ∞ distance and $^1/_2mv^2$ are important quantities in this problem. At this point, it is worth stating that each of these has a “name”:

force ∞ distance is defined as work
$^1/_2$ mass ∞ velocity^2 is defined as kinetic energy.

Variations:

None.

Adapted from:
Unknown.

Science as Inquiry

Work and the Wall

Item:

The term work has a specific meaning in science. Which of the following situations is a good example of work being done on an object in the scientific sense?

A. A person pushes against a wall, but the wall doesn't move.
B. A person holds a book perfectly balanced on his or her head.
C. A person pulls a toy car up a flight of stairs lifting the car a distance of five meters.
D. A person is acted upon by the force of gravity when standing still.

Justification:

Using the scientific meaning of the word work, think about the last lab activity done in class. Explain who did the most amount of work and who did the least amount of work during the lab activity. How could you measure the amount of work done by each person?

Answer:

Based on the idea that work = force ∞ distance, or simply that a net change in position must occur in order for work to be done:

A. No motion, no work.
B. Same as A.
C. Motion, work is done.
D. Same as A.

Science as Inquiry

Pat’s Job

Item:

Pat likes to jog five km each morning. Recently, she decided to take her dog along with her on her runs. Pat weighs 120 pounds and the dog weighs 20 pounds. During their jog, Pat and her dog ran up a hill, increasing their elevation by 200 feet. Which of the following statements is true about the work done by Pat during her jog up the hill?

A. Pat does more work than her dog because she weighs more.

B. The dog does more work because it is smaller but climbs just as high as Pat.

C. They do the same amount of work because they climb the same total distance.

D. The dog does more work because it actually climbs farther during the run than Pat does, because it is smaller.

Justification:

How do you determine how much work has been done?

Answer:

A. Work = Force ∞ distance. In this scenario, the force of gravity as measured by weight. Since the distance is the same, but Pat weighs more, Pat does more work.

Science as Inquiry

Falling Leaf & Work

Item:

Consider a grove of eucalyptus trees whose average height is approximately 40 feet. When a leaf falls from the top of a tree to the ground, is work being done? Explain the work and energy changes that occur.

Answer:

Science and Technology/History and Nature of Science

Work and Kinetic Energy

Item:

Many years ago, in war, an army would use a woden tree trunk called a "battering ram" to knock down the doors of a castle. To make the ram most effective, soldiers should:

A. Move the ram as rapidly as possible a large distance to hit the door.

B. Apply a large force by pressing the ram hard against the door.

C. Find as light a tree as possible to reduce the mass of the ram, so less force was needed to lift it.

D. Throw the ram from the furthest possible distance away so it gains momentum before hitting the door.

Justification:

Explain the physics of how the battering ram works on breaking down a door. Include force diagrams and terms such as work and energy in your answer. If an iron pole had been available, would this have been more effective, and why?

Answer:

A. The maximum energy gain is force applied ∞ distance. The most kinetic energy will have the greatest effect on breaking the door.

In the Justification, students may hit also on the idea of a sharpened point, meaning force per unit area being more effective, as well as the ideas of work/energy of moving pole. Since iron has a higher density than wood, can use the same mass—smaller pole, or same volume—higher mass, and get more effect.

Note: Urban students in Los Angeles and Philadelphia (others?) may be familiar with modern police rams used to effect entry into drug strongholds.

Science as Inquiry

Mass & Speed

Item:

An object with a speed of 20 meters per second has a kinetic energy of 400 joules. The mass of the object is:

A. 1 kilogram
B. 2 kilograms
C. 0.5 kilograms
D. 40 kilograms.

Justification:

Explain your reasoning for this question.

Answer:

Science as Inquiry

Speed & Kinetic Energy

Item:

If the speed of an object is doubled, its kinetic energy will be:

A. halved
B. doubled
C. quartered
D. quadrupled.

Justification:

What is the formula for kinetic energy?

Answer:

Science as Inquiry

Falling Freely

Item:

A 20 kilogram object strikes the ground with 1,960 joules of kinetic energy after falling freely from rest. How far above the ground was the object when it was released?

A. 10 meters
B. 14 meters
C. 98 meters
D. 200 meters.

Justification:

Explain your reasoning for this question.

Answer:

Science as Inquiry

Dropping the Ball

Item:

A 0.10 kilogram ball dropped vertically from a height of 1.0 meters above the floor bounces back to a height of 0.80 meters. The mechanical energy lost by the ball as it bounces is approximately:

A. 0.080 joules
B. 0.20 joules
C. 0.30 joules
D. 0.78 joules.

Justification:

Explain your reasoning for this question.

Answer:

Science as Inquiry

Work Force

Item:

Work is being done when a force:

A. Acts vertically on a cart that can only move horizontally.
B. Is exerted by one team in a tug-of-war when there is no movement.
C. Is exerted while pulling a wagon up a hill.
D. Of gravitational attraction acts on a person standing on the surface of the Earth.

Justification:

What is the definition of work?

Answer:

Science as Inquiry

Jack Force

Item:

A jack exerts a force of 4,500 Newtons to raise a car 0.25 meters. What is the approximate work done by the jack?

A. 0,000,056 joules
B. 1,100 joules
C. 4,500 joules
D. 18,000 joules.

Justification:

Explain your reasoning for this question.

Answer:

Science as Inquiry

Acceleration

Item:

A tennis ball and a solid steel ball of the same size are dropped at the same time. In the absence of air resistance, which ball has the greater acceleration?

A. The tennis ball.
B. The steel ball.
C. They both have the same acceleration.
D. It is impossible to determine.

Justification:

Define acceleration.

Answer:

Science as Inquiry

Designing Vehicles

Item:

Have students propose designs for a more efficient vehicle for a specified use (e.g., transport of items at school; lifting a large rock to a higher location on a slope; etc.).

Answer:

Science as Inquiry

No Work?

Item:

If an object moves through a distance without an external force, why is there no work done? If a force is applied to an object without it moving, why is there no work done?

Answer:

Science as Inquiry

Battering Ram

Item:

About 1,000 years ago, soldiers who wanted to knock down the wooden doors of a castle would use a long heavy pole called a "battering ram." Explain how a fast-moving battering ram can do such damage to wooden doors.

Answer:

Science in Personal and Social Perspectives

Energy Sources

Item:

Students do research to find which fuel (energy source) is the least destructive to our environment. They should consider fossil fuels, methanol, ethanol, electricity and solar energy.

Answer:

Science as Inquiry

Match This!

Item:

Part A. Does the property of tires have an effect on the acceleration of a car? Students will use Matchbox Cars (standard size) and race them down a ramp. Then students construct tires of different materials and/or sizes to see if there is a change in the speed and/or distance their car travels.

Part B. Relate State Police skid mark charts to speed at the time brakes are applied. Is this a valid measurement? Give sound, scientific reasons for your answers.

Answer:

Science as Inquiry

Dueling Skateboards

Item:

Place one skateboard in a stationary position at the midway point on a ramp. Let a second skateboard come down the ramp and hit the first skateboard—propelling it forward. Put bricks on the board and see if the difference in mass has any influence.

Answer:

Science as Inquiry

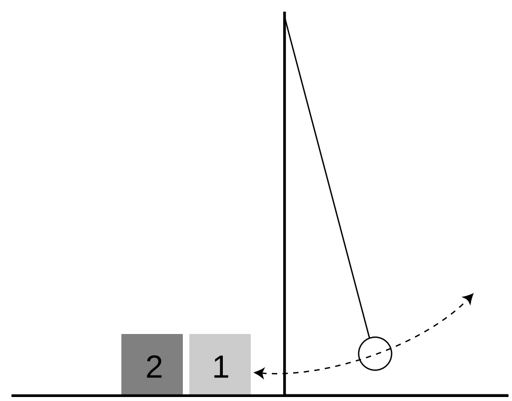
Force & Mass

Item:

What is the relationship between force and mass?

Materials. pendulum, 2 blocks of equal size, ruler, tape (or marker).

Procedure. Set up the materials as shown in the figure, but first using only 1 block. Mark the starting point of the block with a piece of tape, release the metal ball of the pendulum and let the ball freely strike the block. Using a ruler, measure the distance the block traveled. Repeat the procedures three times to get more accurate data. Record the data in a table. Now, add the second block, as shown in the figure, and repeat the experiment.



Answer:

Consumables

Item	Quantity (per lab group)	Activity
automobiles of different masses	2	1
bathroom scales	2	1
bricks (or books)	—	2*, 3*
hanging masses	—	2*
masking tape	—	1
pulley	1	2*
string	—	2*
ramp	1	3*
ticker tape	—	1
ticker-tape timer	1	1
ticker-tape timer (or sonic ranger)	1	2*, 3*

Non-Consumables

Item	Quantity (per lab group)	Activity
balance	1	2*
lab cart	1	2*, 3*
meter stick (or tape measure)	1	1, 3*
spring scale	1	2*, 3*

*indicates alternative or additional activity

Key:
1. A Moving Experience
2. Move It!
3. Give Me A Brake!