SCOPE, SEQUENCE, and COORDINATION

A National Curriculum Project for High School Science Education

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SCOPE, SEQUENCE, and COORDINATION

SS&C Research and Development Center
Bill G. Aldridge, *Principal Investigator and Project Director**
Dorothy L. Gabel, *Co-Principal Investigator*
Erma M. Anderson, *Associate Project Director*
Stephen Druger, *Project Associate for Micro-Unit Development*
Nancy Erwin, *Project Editor*
Rick McGolerick, *Project Coordinator*

Evaluation Center
Frances Lawrenz, *Center Director*
Doug Huffman, *Associate Director*
Wayne Welch, *Consultant*
University of Minnesota, 612.625.2046

Houston SS&C Materials Development and Coordination Center
Linda W. Crow, *Center Director*
Godrej H. Sethna, *School Coordinator*
Martha S. Young, *Senior Production Editor*
Yerga Keflemariam, *Administrative Assistant*
Baylor College of Medicine, 713.798.6880

Houston School Sites and Lead Teachers
Jefferson Davis H.S., Lois Range
Lee H.S., Thomas Goldsbury
Jack Yates H.S., Diane Schranck

California Coordination Center
Tom Hinojosa, *Center Coordinator*
Santa Clara, Calif., 408.244.3080

California School Sites and Lead Teachers
Sherman Indian H.S., Mary Yarger
Sacramento H.S., Brian Jacobs

Iowa Coordination Center
Robert Yager, *Center Director*
Keith Lippincott, *School Coordinator*
University of Iowa, 319.335.1189

Iowa School Sites and Lead Teachers
Pleasant Valley H.S., William Roberts
North Scott H.S., Mike Brown

North Carolina Coordination Center
Charles Coble, *Center Co-Director*
Jessie Jones, *School Coordinator*
East Carolina University, 919.328.6172

North Carolina School Sites and Lead Teachers
Tarboro H.S., Ernestine Smith
Northside H.S., Glenda Burrus

Puerto Rico Coordination Center**
Manuel Gomez, *Center Co-Director*
Acenet Bernacet, *Center Co-Director*
University of Puerto Rico, 809.765.5170

Puerto Rico School Site
UPR Lab H.S.

* * * * * * * * * * * *

Pilot Sites
Site Coordinator and Lead Teacher
Fox Lane H.S., New York, Arthur Eisenkraft
Georgetown Day School, Washington, D.C., William George
Flathead H.S., Montana, Gary Freebury
Clinton H.S., New York, John Laffan**

* Western NSTA Office, 894 Discovery Court, Henderson, Nevada 89014, 702.436.6685
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National Science Education Standard—Physical Science

Motions and Forces

Objects change their motion only when a net force is applied. Laws of motion are used to calculate precisely the effects of forces on the motion of objects. The magnitude of the change in motion can be calculated using the relationship $F = ma$, which is independent of the nature of the force. Whenever one object exerts force on another, a force qual in magnitude and opposite in direction is exerted on the first object.

Teacher Materials

Learning Sequence Item:

918

Newton's Second Law

October 1996
Adapted by: Stephen Druger

Dynamics and Newton's Laws of Motion. Students should use spring balances to measure forces and, using carts and spring scales, observe the motion of objects of different mass under the action of the same force. With these observations, students will gain a qualitative understanding of Newton's second law (*Physics, A Framework for High School Science Education, p. 11*).

Contents

This micro-unit was adapted by **Stephen Druger** (Northwestern University, Evanston, Ill.)

918

Learning Sequence

Dynamics and Newton's Laws of Motion. Students should use spring balances to measure forces and, using carts and spring scales, observe the motion objects of different mass under the action of the same force. With these observations, students will gain a qualitative understanding of Newton's second law (*Physics, A Framework for High School Science Education, p. 11*).

Science as Inquiry	Science and Technology	Science in Personal and Social Perspectives	History and Nature of Science
Weighing the Masses **Activity 1** Moving the Masses **Activity 2** It's a Downhill Battle **Activity 3** Sled Ride **Assessment 1** Mass and Acceleration **Assessment 2** Weight and Mass **Assessment 3**		Sled Ride **Assessment 1**	

Suggested Sequence of Events

Event #1

Lab Activity

1. Weighing the Masses (20 minute)

Event #2

Lab Activity

2. Moving the Masses (50 minutes)

Event #3

Lab Activity

3. It's a Downhill Battle (50 minutes)

Event #4

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

Suggested readings:

Macaulay, D., "Springs." Pp. 82–83 in *The Way Things Work*. Boston: Houghton Mifflin Company, 1988.
Gamov, G., ""God Said, 'Let Newton Be!'" Chapter 3 in *Biography of Physics.* New York: Harper & Brothers, 1961.
March, R.H., "The Denouement: Newton's Laws." Chapter 3 in *Physics for Poets*. McGraw-Hill, Inc., 1978.

Assessment items are at the back of this volume.

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

Weighing the Masses

How is weight related to mass?

Overview:

In this activity students use a spring balance and compare its operation with that of a beam balance. They learn that while a beam balance determines the gravitational mass of a sample by measuring it against a set of calibrated masses, the spring balance measures weight as the force exerted by gravity, Their experiments also suggest that weight is proportional to mass and is smaller when the gravitational acceleration, *g,* is smaller.

Materials

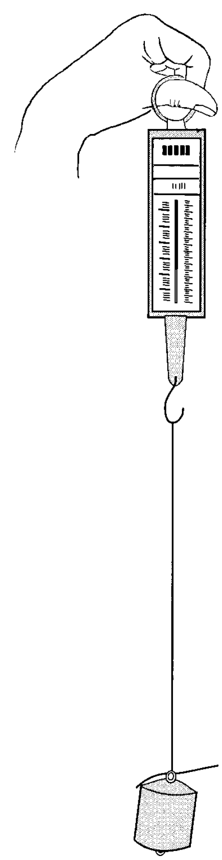
Per lab group:

spring balance (calibrated in newtons)
masses (0.1 kg), 2 or more
string

Procedure:

Have students adjust the spring balance to read zero with the string attached. They then suspend a 0.1-kg mass from the balance. They should note the reading on the scale and use a ruler to measure how far the indicator moved (and therefore how far the spring has been stretched).

Students then tie the second mass to the string and take another reading and length measurement. They then cut the string and allow the masses to fall onto the newspaper or other cushioning beneath, observing whether the masses appear to strike the ground at the same time.



Background:

It is important to distinguish between weight, which is the force of gravity on an object, and mass. To describe mass as merely "the amount of matter" is oversimplified in the context of classical mechanics, where it has a more precise meaning in terms of the inertia of the object and its gravitational attraction to other objects such as Earth.

The beam balance used by students in micro-unit 910 measures the amount of a substance by comparing its weight with the weight of standardized masses on the other pan. Since the weight, regarded as the force exerted by gravity on each side of the balance, is proportional to mass, *m*, the weights on the two sides are equal when the masses on both sides are equal. Using the beam balance to measure mass in this way would give the same results in an environment where gravity was weaker, for example, on the moon.

Mass measured in this way may be referred to as "gravitational mass." In contrast, "inertial mass" is the mass measured by subjecting an object to a force, *F*, and observing its acceleration, *a*, in response. Newton's second law, **F = ma,** then defines the inertial mass, *m*. It is a remarkable but basic fact of nature that inertial mass and gravitational mass are the same. The mass, *m*, that enters into Newton's second law of motion relating force, mass, and acceleration is the same mass, *m*, in Newton's law of universal gravitation giving the gravitational attraction between two objects.

Adapted from: none

Teacher Sheet

Science as Inquiry

Moving the Masses

How does a force affect an object free to roll?

Overview:

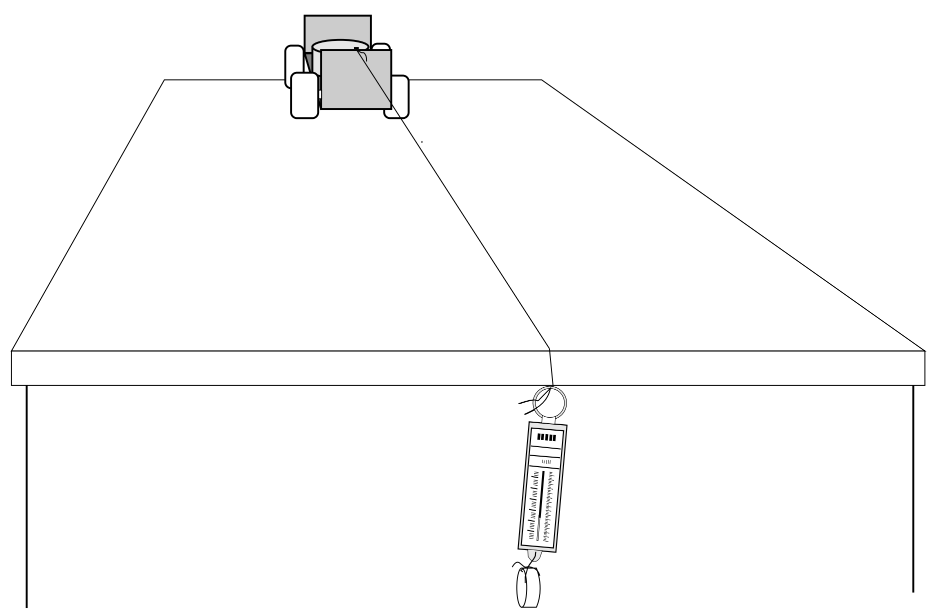
Here students examine the concept of inertial mass by observing how average speed, and therefore acceleration, varies for carts of different mass moved by approximately the same force. They note that approximately the same force (to overcome friction) is required to move an empty lab cart at a very slow constant speed and at a higher constant speed. They also observe that a cart with cargo (a more massive cart) is *accelerated* less by the same applied force than is the empty cart.

Materials:

Per lab group:
lab cart (1–2 kg)
masses (10 g), 2
spring balance
stopwatch (or digital watch with stopwatch capability)
string

Procedure:

Have students tie the spring balance to the cart with string and measure what force it takes to pull the cart at a steady rate against friction. They should take care to pull the cart so that the string is horizontal. They then repeat the procedure with second mass added to the cart. They should observe only a small change, attributable to slightly different frictional effects, in the force needed.



Next, have students tie a string to the cart and suspend the spring balance with an attached mass from the free end as shown. An obstacle near the end of the table can be positioned to stop the cart from rolling over the edge.

Students then release the cart, and it is set into motion by the weight of the mass hanging over the edge of the table. They should carefully observe the reading of the spring balance as the cart and mass accelerate, noting that the force the small hanging mass exerts on the cart, as indicated by the balance reading, hardly changes from its value when the cart is stationary.

Students now remove the spring balance, allowing the cart to be pulled directly by the suspended mass. After releasing the cart students time how long it takes to reach the edge of the table. Another mass is then added to the cart as cargo, and the time required to travel the distance is again measured. The time is fairly short in both cases, so averaging over repeated trials is especially helpful for getting meaningful data.

If the frictional forces opposing the motion of the cart are noticeably different with and without the added cargo, a third trial should be made with a correction for friction. Using the spring balance, students in this third trial select a mass whose weight is about equal to the already measured change in frictional force when the cargo is added to the cart. They should tie the additional mass to the string and again time the cart and cargo. The added weight approximately counteracts the slight increase in frictional force resulting from the added cargo.

Background:

The slight force needed to pull the cart at a constant speed against frictional resistance is immediately observed to be far smaller than that used in accelerating the cart to its final speed. Students will also note that keeping the cart moving at a greater constant speed does not involve a significantly greater force. Unfortunately, observably greater frictional resistance is likely to result with the cargo added, but again it is a small effect compared with the force needed to set the cart in motion.

While not a clear-cut demonstration of Newton's first law, since friction is always present to promote the usual preconception that a moving object requires the continual application of a force, this activity should help demonstrate that the magnitudes of the different forces involved are consistent with the concept of inertia introduced in micro-unit 915. Newton's third law, that there is an equal but oppositely directed reaction force when one object exerts a force on another, was examined in activity 917.

The main intent of this activity is to illustrate phenomenologically Newton's second law, **force = mass × acceleration**, by introducing the concept of inertial mass. If a cart of infinite mass is held stationary, the tension in the string is the weight, mg, of the mass, m, suspended over the edge of the table. If the cart instead had negligible mass, both the cart and the hanging mass would accelerate together at the rate $\boldsymbol{g} = \mathbf{9.8\ m/s^2}$, with the negligible inertia of the cart providing little resistance to the acceleration and producing no significant tension in the string. It follows that in the present intermediate case, where the mass of the cart is very large but not infinite compared with the suspended mass, the tension in the string when the cart accelerates is only a little less than ma. Students, by using the spring balance as described, will find that the weak acceleration of the cart with and without cargo produces only minor changes in the force that the suspended mass exerts, with these changes being in the wrong direction to account for the slower acceleration of the more massive cart.

More precisely, disregarding friction, the total mass being accelerated times its acceleration, $(M+m)a$, is equal to the force, mg, of gravity on the suspended mass, m, so that the acceleration, a, experienced by the cart is therefore *m/(M+m)* times *g*. For *M* much greater than *m*, this is very close to *(m/M)g.* An even more detailed analysis would give the lowest-order correction from the expansion

$$a = m/(M+m)g = (m/M)\ [1- (m/M) + (m/M)^2 \cdot\cdot\cdot\ ]g,$$

showing that the fractional change in tension that results from allowing the system to accelerate rather than holding it in position is approximately *m/M,* which, for a 20-g mass pulling a 2-kg cart, is a mere 0.1%. This is well below the resolution of measurement of the experiment.

Students at this level are not expected to analyze mathematically the effect of acceleration on the tension in the string, but are merely expected to observe phenomenologically that the small acceleration of the massive cart causes little change in the force exerted by the string.

Depending upon the quality of the cart and the surface of the table, there might be observable changes in the weak frictional forces opposing the acceleration of the cart when the cargo is added. These arise mainly from frictional forces within the wheels. Should measurement show the change in frictional force to be substantial, a rough correction can be made by adding additional weight (approximately equal to the already measured difference in frictional forces) to that supported by the string.

Adapted from: none

Science as Inquiry

It's a Downhill Battle

How do changes in mass affect rolling down an incline?

Overview:

In this activity students observe that a lab cart on an inclined plane experiences a force proportional to its mass. The cart tends to accelerate along the plane but nevertheless moves from its resting position with essentially the same average speed (and therefore the same acceleration) as when extra cargo is added. Students are led to conclude that if the mass of the cart is increased, the increases in gravitational force and inertia counteract each other to produce no change in how the cart rolls down the incline (disregarding the small change caused by differences in frictional effects).

Materials:

Per lab group:
lab cart (1–2 kg)
masses (10 g), 2
spring balance
stopwatch (or digital watch with stopwatch capability)
desk-length or longer board to use as inclined plane
(table may be propped up on one side as an alternative)

Procedure:

Students place the cart on an inclined plane. This may be a large flat board propped up slightly on one end or a worktable with its legs propped up on one side. The incline should be great enough so that the cart will roll when released but small enough that the time of travel will be more than a second or two, allowing the time to be measured.

Using the spring balance students measure the force along the direction of the inclined surface needed to keep the cart from rolling. This gives the force that tends to accelerate the cart. The mass of the cart should also be measured. Students then repeat the process with extra mass of about 1 kg added.

Students then place the empty cart at a marked location on the incline, release the cart, and time how long it takes it to reach a lower marked point. This should be repeated a few times and averaged to get more accurate results. Then they repeat the entire process with the extra mass added to the cart, observing whether the time the cart takes to travel the distance is significantly changed.

Background:

The force acting on the cart along the direction of the incline is a component of the gravitational force in that direction. It depends on how much the surface is inclined with respect to the horizontal and is proportional to the mass, since weight is proportional to the mass. Specifically, for inclination angle *Ø* with respect to the horizontal, the force along the direction of motion of the cart is *mg sin Ø*.

At the same time that the gravitational component of force accelerating the cart along the incline is proportional to mass, Newton’s second law, **F = ma**, implies that the acceleration in response to a given force is inversely proportional to the mass. The overall effect of the increased mass through both effects is to cause the same acceleration, and therefore the same motion, of the empty and cargo-laden carts (apart from minor differences in frictional effects).

Thus the cart moves in the same way with the added mass because the increased force accelerating the cart is counteracted exactly by the increased inertia of the cart, with only minor differences produced by frictional effects. Implicit in this is the equivalence between the gravitational mass that produces the force and the inertial mass that controls the acceleration the force produces.

Adapted from: none

Science as Inquiry/
Science in Personal and
Social Perspectives

Sled Ride

Item:

Suppose a student is on a sled that can slide with no friction at all on a large sheet of ice. Another student (with high-traction shoes) pushes the sled until its speed reaches 1 m/s and then suddenly stops pushing and lets go of the handle bars. The sled, once it is released:

A. Continues accelerating as it was the moment it was released;
B. Continues at the same speed of 1 m/s;
C. Slows down;
D. Stops.

Answer:

B. It requires a force to change the motion of an object because of its inertia. Since there is no friction and since the sled was released to slide on its own power, it continues moving at the same speed as at the moment it was released.

Science as Inquiry

Mass and Acceleration

Item:

If the mass of an object is increased, a force applied in the absence of frictional forces:

A. Accelerates the object more strongly;
B. Causes it to move with a greater constant speed;
C. Causes it to move at a slower but constant speed;
D. Accelerates it more slowly.

Answer:

D. As long as there is a net force applied, the object accelerates, so B and C are incorrect. But greater mass means greater inertia, or greater resistance to changes in motion, when a force is applied and therefore less acceleration.

Science as Inquiry

Weight or Mass?

Item:

You want to see which is heavier, a small box filled with iron filings or one filled with lead filings. When you hold both stationary, one in each hand, to compare the effort it takes to hold them, are you directly comparing their weight or their mass? How about when you hold one in each hand and compare their resistance to being moved up and down?

Answer:

Students are expected to explain that when holding the boxes stationary, they would directly feel the force of gravity on each, which is the weight of the boxes. When moving the boxes up and down, students would be comparing their relative resistance to changes in motion and therefore their masses.

Consumables

Item	Quantity per lab group	Activity
string	—	1, 2

Nonconsumables

Item	Quantity per lab group	Activity
board (desk-length) or table	1	3
lab cart (1–2 kg)	1	2, 3
masses (100 g)	2 or more	1
masses (10 g)	2	2, 3
spring balance (calibrated in newtons)	1	1, 2, 3
stopwatch (or digital watch with stopwatch capability)	1	2, 3
worktable	1	2

Key to activities:

1. Weighing the Masses
2. Moving the Masses
3. It's a Downhill Battle