OPPS

Operation Primary Physical Science

Moving Objects

Workshop Leader's Guide

Department of Physics and Astronomy- Louisiana State University

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Workshop Outline

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7. **INQUIRE: Are Some Things Harder to Accelerate Than Others?**
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   - C. Apply
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Workshop Sequence

I. ELICIT

What Do We Know about Moving Objects?

Research has shown that most learners hold an Aristotelian view of moving objects; namely, motion implies force (Clements,1983). Related propositions that learners frequently embrace include:

1) When a force is applied to an object, it produces motion in the direction of the force;
2) Under the influence of a constant force, objects move with constant velocity;
3) The velocity of an object is proportional to the magnitude of the applied force;
4) In the absence of a force, objects are either at rest, or if moving, slowing down.

(Minstrell, 1982; Gunstone, R., 1987; Hashweh, 1988; Lythcott, 1985)

This activity, adapted from the Workshop Physics program of Priscilla Laws, et al, has been designed to elicit some of these commonplace notions about motion. Without actually doing the activity, teacher are asked to describe how they think they should hit a bowling ball with a croquet mallet to make the ball move across a hard level floor with a constant speed, with an increasing speed, and in a circle. Teachers share their predictions and discuss the reasons for them before continuing to the next activity where they will have an opportunity to test out their ideas.

II. EXPLORE

What Can We Find Out about Moving Objects?

Teachers are given the opportunity to actually use a croquet mallet and bowling ball to test their ideas about motion. Depending on the number of bowling balls and the croquet mallets available, the activity may be done as a whole group or in small groups. The activity requires a smooth, hard level floor.

Workshop Sequence

III. INQUIRE

How Do We Get There from Here?

While it is understood that most, if not all, participants come to the workshop with a basic knowledge of these concepts, there are several important reasons to begin at this point. First is that the participants may have a certain comfort level in teaching these concepts, as many of them appear in primary mathematics curriculums. This will give the workshop leaders an opportunity to discuss with teachers other related activities they already do with students and open the door to a discussion of integrating science into the curriculum. Secondly, the National Science Education Standards (NSES) K-4 content standards specifically address "Science and Technology," “Science in Personal and Social Perspectives" as well as "History and Nature of Science." The history of the development of technology to measure distance and time, and the social implications of this development, is a rich one. At this point, the workshop leader can easily model and discuss how these standards can be met.

The first activity sets the stage for the need for standards of measuring distance and direction by having participants attempt to find a point in the room. Other activities define and apply measurements of distance and direction. The need to accurately define time is also explored.

A. Blindfold Navigation

One member of each team is asked to leave the room while the remaining members write a set of instructions that will guide him or her from the doorway to a predetermined spot in the room while blindfolded. The follow-up discussion focuses on the need for consistent methods of measuring both distance and direction, as well as some of the historical and social perspectives.

B. Measuring Distance and Direction

Participants are asked to estimate distances (width of their finger, height of the room, etc). Estimates are then checked using a meter stick. Similarly, participants are asked to set up a coordinate system and determine the directions from where they are to points in the room. Estimates are checked with a large protractor. (A compass may also be used for this activity.) A discussion of displacement unites the concepts in this activity.

C. Measuring Time

Individuals are asked to determine when a minute has elapsed (+/- 5 seconds) without using any instruments. As few people can do this, it serves to underscore the need for instruments to measure time and will be used to initiate a discussion of what is required to define and measure time, as well as some of the historical solutions.

Workshop Sequence

III. INQUIRE cont.

D. Make Sense
Teachers try to make sense of what they have learned by writing important ideas on large chart paper. They also review questions they have about distance, direction, and time.

E. Apply
One member of each team is asked to leave the room while the remaining members measure the direction and distance from the doorway to an object in the room and write results on a card. The missing member is then given the card, a protractor, and a meter tape and will attempt to identify which object was chosen.

IV. INQUIRE

What Is The Meaning of Velocity?

A. What is Speed?
Each group is given a toy electric car that travels at a relatively constant speed. Using a meter stick and stopwatch, they are asked to design and conduct an experiment to measure the car's speed. The results are compared to determine which group's car was the fastest. As each group may have used a different definition of speed (the time to go a set distance, time/distance, etc.) or different units, the comparison may be difficult. This leads to the necessity for a uniform definition of speed and the opportunity to introduce it.

B. Is the Speed Constant?
Participants are asked to determine the speed of a "pull back" type toy car that is released on a horizontal surface. Because these cars slow down as they travel, they can be used to illustrate the concept of average speed. By encouraging the participants to break the trip into smaller segments, the concept of instantaneous speed is explored. A discussion of average and instantaneous speed in the story "The Tortoise and the Hare" serves as a follow-up.

C. Graphing Speed
Participants go outside or to a long corridor to measure the distance and time of people as they run a 25 meter course. Timers are stationed every 5 meters and they measure the time from the beginning spot to their location. This produces a data table of distance and time that can be graphed. By having different people run different ways (constantly slow, constantly fast, speeding up, slowing down) participants can compare the raw data, the graphs, and the speeds over different segments.

D. Velocity Isn't Speed
This activity, in which teachers walk in different directions, emphasizes the difference between speed and velocity.

Workshop Sequence

IV. INQUIRE cont.

E. Make Sense
What have we learned about velocity?

F. Apply
Each group will be asked to find the average speed of a common motion (walking, running, biking, or a car going by the building). The results of the groups will then be shared.

V. INQUIRE

How Many Ways Can Velocity be Changed?

Participants will explore acceleration starting with "feeling" acceleration in a straight line, then learning how to calculate it. They will then explore changing direction as a form of acceleration.

A. Feeling Acceleration
A bowling ball is placed on the floor, and a participant is asked to tap on the side of it with a croquet mallet at a constant rate. As the ball picks up speed, the participant will have to move faster and faster to keep up with it, graphically illustrating the concept of acceleration.

B. Measuring Acceleration
How acceleration can be calculated is developed by using a zip line (weight on a pulley that travels across the room on an inclined string).

C. Three Ways to Change Velocity
The participants will discover how to change velocity by increasing speed, decreasing speed, or turning.

D. Make Sense
What have we learned about acceleration?

E. Apply
Participants will be asked to calculate the acceleration of air pucks as they travel up or down an inclined surface.

Workshop Sequence

VI. INQUIRE

What Does It Take to Make Things Accelerate?

The Inquire begins with an investigation into the causes of acceleration. The concept of force is then developed, including its origin and measurement. The effects of balanced and unbalanced forces are explored and Newton's first and second laws are introduced and applied.

A. What Causes Acceleration?
The activity used in the Elicit/Explore (moving a bowling ball in a figure eight pattern using a croquet mallet) is redone. This time the participants are asked to focus their attention on when the velocity is constant and when it is changing. What does it take to get it going? How about to keep it going? ...to turn?...to stop? Participants are then asked to reconsider the activities in the last Inquire and determine what caused the acceleration.

B. What Is Force?
Participants brainstorm examples of forces in everyday life. Participants share their ideas about the relationship between force and motion. Gravity and friction, two forces that affect almost all everyday motions, are demonstrated and discussed. [NOTE: Keep in mind that the focus of this module is Motion. This brief overview of forces provides participants only with what they need to know to identify why the motion of an object may change.]

C. Balanced and Unbalanced Forces
The workshop leader uses a roller skate attached to a spring scale to discuss and demonstrate the idea that an object is at rest or moving with a constant velocity when the forces on it are unbalanced.

D. Make Sense
What have we learned about forces and acceleration?

E. Apply
Participants build a marble "roller coaster" containing hills, valleys, straight-aways, and turns using flexible half-round track. They describe the net force and the resulting type of motion in each section of the track.

Workshop Sequence

VII. INQUIRE

Are Some Things Harder to Accelerate than Others?

A. Inertia
Objects of varying mass will be hung from the ceiling. Participants will attempt to accelerate them by blowing through a straw leading to a discussion of mass vs. weight.

B. Make Sense
What have we learned about forces, acceleration and inertia? Participants will be given a brief description of the notion of the causes of motion in Aristotelian physics. They will be asked to refute these notions using what they have learned in the workshop.

C. Apply
Participants will be asked to predict the how the initial Explore/Elicit activity would work if the bowling ball was replaced by a soccer ball. They will then check their predictions by playing it with a soccer ball.

VIII. REFLECT

What Have We Learned about Moving Objects?

For participants to reflect on what they have learned, and how they have learned, during the workshop.

Master Materials List

I. Elicit

- no materials required for this activity

II. Explore

- bowling ball
- croquet mallet
- smooth, hard level floor
- 2 chairs
- stopwatch
- masking tape
- chart paper and markers

III. Inquire

III-A. Blindfold Navigation
For each group:
- blindfold (a bandanna works well)
- writing materials
- masking tape
- meter stick

III-B. Measuring Distance And Direction
For each group:
- meter sticks
- protractors (large, blackboard type is best)

III-C. Measuring Time
For the whole group:
- stopwatch

III-D. Make Sense
- no materials required for this activity

III-E. Apply
- meter sticks (or longer tape measures, if available)
- protractor (large, blackboard type is best)

IV. Inquire

IV-A. What Is Speed?
For each group:
- toy electric car that travels at a constant speed
- stopwatch
- meter sticks

IV-B. Is The Speed Constant?
For each group:
- "pull back" type toy car that slows down as it travels
- stopwatch

IV. Inquire (cont.)

IV-D. Velocity isn't Speed
For each group:
- stopwatch
- meter stick or tape measure

IV-E. Make Sense
- no materials required for this activity

IV-F. Apply
For each group:
- stopwatch
- meter sticks or metric tape measure

V. Inquire

V-A. Feeling Acceleration
For each group:
- bowling ball
- croquet mallet
- chair

V-B. Measuring Acceleration
For each group:
- string (cotton works well, avoid string that stretches easily)
- small pulley
- object of approximately 50g to hang on pulley
- meter stick
- stopwatch

V-C. Three Ways To Change Velocity
For each group:
- balloon
- air puck
- table with smooth level top

V-D. Make Sense

- no materials required for this activity

V-E. Apply
For each group:
- air puck
- table with smooth level top
- material to raise one end of the table
- tape
- thread

VI. Inquire

VI-A. What Causes Acceleration?
For each group:
- bowling ball
- croquet mallet

Master Materials List

VI. Inquire (cont.)

VI-C. Balanced and Unbalanced Forces

For each group:

- board (at least 3 feet long)
- books (to make incline plane)
- roller skate
- spring scale

VI-D. Make Sense

- no materials required for this activity

VI-E. Apply

For each group:

- marble
- several sections of half round flexible foam pipe insulation
- tape or other method of attaching the sections of insulation
- chairs, books or other materials to form the insulation into hills, etc

VII. Inquire

VII-A. Inertia

For each group:

- straws

Materials for the workshop leader:

- film cans
- sand
- string
- scissors

VII-B. Make Sense

- no materials required for this activity

VII-C. Apply

For each group:

- soccer ball
- croquet mallet
- 2 chairs

Key Ideas about Moving Objects

1. The position of an object can be described by locating it relative to another object or the background.

The location of an object can be described by stating its distance and direction from another object or reference point. Distance may be measured using a ruler, measuring stick, measuring tape or other appropriate instrument. Terms such as left, right, above, or below may be used to describe the direction of an object from a reference point. Direction may also be measured by using a compass positioned at the reference point, and reading the number of degrees the object is from a specified reference direction. A reference background or system, such as the lines of latitude and longitude that appear on globes and maps, provide another way of describing the location of an object.

2. An object's motion can be described by tracing and measuring its position over time.

The word "motion" implies that there is a change in position over time. An object in motion moves a certain distance in a given time. Speed measures how fast something is moving. Average speed is the distance an object travels divided by the time of travel.

$$\text{Average speed} = \Delta\text{distance}/\Delta\text{time}$$

Instantaneous speed is the speed that an object has at any given instant. Instantaneous speed is determined by finding the average speed over an infinitesimally small time interval. (Example: The speedometer of a car indicates the instantaneous speed but is actually determined by finding the average speed during a single revolution of the tires.) Velocity describes not only how fast an object is moving but also specifies in what direction. Sometimes people loosely use the term "velocity" interchangeably with "speed," but there is a distinct difference. Velocity is speed and direction. (Example: A car travels at 60 km/hr to the north)

3. Motion can be changed by increasing or decreasing the speed of an object and/or changing the direction of its motion.

Because velocity is both speed and direction, the velocity of an object changes whenever it speeds up, slows down, or changes direction (such as going around a curve). Whenever the velocity of an object changes in any of these ways, we say that an object accelerates. Acceleration describes how quickly the velocity changes:

$$\text{Acceleration} = \Delta\text{ velocity}/\Delta\text{time}$$

NOTE: Many people erroneously define acceleration as simply "change in velocity." It is actually the "rate at which velocity changes." EXAMPLE : It takes 4 seconds for a remote-controlled model airplane traveling north at 10 meters/second to speed up to 18 meters/second in the same direction. In this example, the change in velocity of the airplane is 8 meters/second to the north, and the acceleration is 2 meters/second/second or 2 m/s^2.

Key Ideas about Moving Objects

4. In the absence of forces such as gravity or friction, an object will keep its speed and direction of motion.

If an object moves at a constant velocity, then there are either no forces acting on it, which is unlikely in the real world, or any forces acting on it are balanced (net force = 0). Similarly, if an object is at rest, then any forces acting on it are balanced (net force = 0). An object at rest can be thought of as having a constant velocity of zero.

5. The motion of an object can be changed by an unbalanced (or net) force.

If the velocity of an object is changing, there is an unbalanced force acting on the object (net force is not equal to zero). A net force acting on an object in the direction of its motion will increase the speed. A net force acting opposite to the direction of motion of the object will decrease the speed. A net force acting at a right angle to the motion of the object will change the direction of motion. A net force acting at any other angle will change both the speed and the direction of motion.

6. The quickness with which an object changes its motion is related to the mass of the object and the size of the force acting on it.

Mass (inertia) is the resistance to acceleration and depends on the quantity of matter in an object. Mass is not a force. (Weight, on the other hand, is a force. "Weight is a measure of the force of gravity acting on an object.) The greater the mass of an object, the greater the force required to accelerate the object. The greater the mass of an object, the less its acceleration when an unbalanced force acts on it.

I. ELICIT What Do We Know about Moving Objects?

GOAL:

To discover teachers' current ideas about moving objects.

OVERVIEW:

Research has shown that most learners hold an Aristotelian view of moving objects; namely, motion implies force (Clements,1983). Related propositions that learners frequently embrace include:

1) When a force is applied to an object, it produces motion in the direction of the force;

2) Under the influence of a constant force, objects move with constant velocity;

3) The velocity of an object is proportional to the magnitude of the applied force;

4) In the absence of a force, objects are either at rest, or, if moving, are slowing down.

(Minstrell, 1982; Gunstone, R., 1987; Hashweh, 1988; Lythcott, 1985)

This activity, adapted from the Workshop Physics program of Priscilla Laws, et al, has been designed to elicit some of these commonplace notions about motion. Without actually doing the activity, teachers are asked to describe how they think they should hit a bowling ball with a croquet mallet to make the ball move across a hard level floor with a constant speed, with an increasing speed, and in a circle. Teachers share their predictions and discuss the reasons for them before continuing to the next activity where they will have an opportunity to test out their ideas.

MATERIALS:

- **none**

I. ELICIT What Do We Know about Moving Objects

For multiple groups to do this activity simultaneously, it is best to use a large open space such as a gym. If this is not possible, it works well in a corridor as a whole group activity, with the group lined up along the wall observing as volunteers move the ball up and down the corridor. This activity should be done on carpet or a hard flat surface such as vinyl flooring or finished wood.

If participants need help "getting started," suggest they talk about where, how often, and how hard they might hit the ball with the mallet in order to produce each of the above motions.

Provide chart paper and markers for the groups to draw or write their ideas for display and sharing.

Let groups, in turn, share their ideas. Do not evaluate ideas; teachers will have the opportunity to test them out in the Explore activity that follows. You can anticipate that most groups' ideas will mimic the misconceptions identified by Clements, et al, which are listed on the previous page. Encourage teachers to not only predict HOW they think the ball should be hit for each type of motion, but to describe WHY they think this. Helping teachers get in touch with their existing ideas and the reasons for them is the first important step in changing their misconceptions.

I. ELICIT: What Do We Know about Moving Objects?

1. Think about, and discuss with your group, exactly how you would use a croquet mallet to hit a bowling ball, initially at rest, to get it to roll on a smooth level floor:

a) in a straight line at a constant speed;

b) in a straight line and speeding up;

c) in a straight line and slowing to a stop;

d) in a circle around a chair;

2. Try to reach a group consensus about each of the above. Then prepare to share your group's ideas with other groups.

II. EXPLORE What Can We Find Out about Moving Objects?

GOAL:

To allow teachers to explore their current ideas about moving objects, to cause teachers to become dissatisfied with these ideas, and to encourage them to begin to search for a more satisfactory model to explain motion.

OVERVIEW:

Teachers are given the opportunity to actually use a croquet mallet and bowling ball to test their ideas about motion. Depending on the number of bowling balls and the croquet mallets available, the activity may be done as a whole group or in small groups. The activity requires a smooth, hard level floor.

ADVANCE PREPARATION

This activity works best if done on a smooth hard floor such as vinyl tile or well maintained wood. On carpet, friction slows the ball down, so the speed is never constant. If the room you must work in is carpeted, a good compromise is to complete the activity and then go into a corridor and have the participants hit the ball hard on that surface and observe and comment on its motion.

MATERIALS:

For the Whole Group:

- bowling ball
- croquet mallet
- smooth, hard level floor
- 2 chairs
- stopwatch
- masking tape
- chart paper and markers

II. EXPLORE What Can We Find Out about Moving Objects

This activity works best if each group can be provided with a bowling ball and croquet mallet. If not, you can conduct the activity with the whole group by calling on individuals from different groups to take turns testing out one of their group's ideas.

Cognitive dissonance occurs when participants discover that their observations are inconsistent with their predictions. Refrain from "teaching" or making judgements during this explore activity, but do encourage teachers to share their observations and inferences.

Select 3-5 volunteers. By hitting the ball with the mallet, each will in turn try to make the ball go in the figure eight pattern as quickly as possible. Members of the class will time the volunteers to see who can do it in the least amount of time. Timing will begin at the first hit and will continue until the ball is back at the mark and at rest. Volunteers will not be allowed to push or pull the ball, only to hit it with the face of the mallet. (This will help simplify observations.)

This is a fairly complicated motion. It includes speeding up, going in a straight line at a constant speed, turning, and slowing down. Do NOT attempt to explain it. Later inquires will give the teachers time to answer questions raised in this activity. The purpose is to give participants the opportunity to focus on the motion and explore their ideas about it. By careful listening and the use of a few questions focusing their attention to sections of the trip, workshop leaders will be able to elicit their ideas about motion and its causes during different parts of the trip. Leaders may suggest that participants diagram the trip in their journals and describe the motion and its causes during different portions of the trip.

Provide participants with chart paper and markers to record their ideas in complete sentences. Allow groups, in turn, to share their ideas and to question the ideas of others.

II. EXPLORE: What Can We Find Out about Moving Objects?

1. Your group will now have a chance to use a croquet mallet and bowling ball to test your ideas about motion. As you do, identify and discuss any of your ideas that may have been incorrect or in need of refinement. Make a note of any new ideas you discover.

2. How would you hit the bowling ball at rest to make it go from a mark (tape on the floor), in a figure eight pattern around two chairs and back to the mark as quickly as possible?

3. Work with your group to make a list of "IDEAS ABOUT MOVING OBJECTS" about which you all agree. These may be new ideas that you developed during this activity, or ideas that you already had prior to the workshop. Periodically during your workshop, your group will have a chance to revisit this list and modify or add to these ideas.

4. Help your group make a list of "QUESTIONS ABOUT MOVING OBJECTS" that you would like to have answered, if possible, during this workshop.

Have participants record their questions on chart paper for display and sharing.

Parts of this activity will be revisited during the course of the workshop so teachers can see if their questions have been answered or their ideas have changed.

III. INQUIRE How Do We Get There from Here?

GOAL:

To introduce the concepts of distance, direction, and time, as well as the means of measuring them.

OVERVIEW:

While it is understood that most, if not all, participants come to the workshop with a basic knowledge of these concepts, there are several important reasons to begin at this point. First is that the participants may have a certain comfort level in teaching these concepts, as many of them appear in primary mathematics curriculums. This will give the workshop leaders an opportunity to discuss with teachers other related activities they already do with students and open the door to a discussion of integrating science into the curriculum. Secondly, the National Science Education Standards (NSES) K-4 content standards specifically address "Science and Technology," “Science in Personal and Social Perspectives," as well as "History and Nature of Science." The history of the development of technology to measure distance and time and the social implications of this development is a rich one. At this point, the workshop leader can easily model and discuss how these standards can be met.

The first activity sets the stage for the need for standards of measuring distance and direction by having participants attempt to find a point in the room. Other activities define and apply measurements of distance and direction. The need to accurately define time is also explored.

III-A. Blindfold Navigation
One member of each team is asked to leave the room while the remaining members write a set of instructions that will guide him or her from the doorway to a predetermined spot in the room while blindfolded. The follow-up discussion focuses on the need for consistent methods of measuring both distance and direction, as well as some of the historical and social perspectives.

III-B. Measuring distance and direction.
Participants are asked to estimate distances (width of their finger, height of the room, etc). Estimates are then checked using a meter stick. Similarly, participants are asked to set up a coordinate system and determine the directions from where they are to points in the room. Estimates are checked with a large protractor. (A compass may also be used for this activity.) A discussion of displacement unites the concepts in this activity.

III-C. Measuring Time
Individuals are asked to determine when a minute has elapsed (+/- 5 seconds) without using any instruments. As few people can do this, it serves to underscore the need for instruments to measure time and will be used to initiate a discussion of what is required to define and measure time as well as some of the historical solutions.

III-D. Make Sense
Teachers try to make sense of what they have learned by writing important ideas on large chart paper. They also review questions they have about distance, direction, and time.

III-E. Apply
One member of each team is asked to leave the room while the remaining members measure the direction and distance from the doorway to an object in the room and write it on a card. The missing member is then given the card, a protractor, and a meter tape and will attempt to identify which object was chosen.

SCIENCE IDEAS

- The position of an object can be described by locating it relative to another object or the background. (NSES)
- Distance, direction, and time must be defined, and a means of measuring them need to be determined in order to accurately describe motion.

III. INQUIRE How Do We Get There from Here?

MATERIALS:

III-A. Blindfold Navigation
For each group:
- blindfold (a bandanna works well)
- writing materials
- masking tape
- meter stick

III-B. Measuring Distance and Direction
For each group:
- meter sticks
- protractors (large, blackboard type is best)

III-C. Measuring Time
For the whole group:
- stopwatch

III-D. Make Sense
- no materials required for this activity

III-E. Apply
- meter sticks (or longer tape measures, if available)
- protractor (large, blackboard type is best)

III. INQUIRE How Do We Get There from Here?

A. Blindfold Navigation

After a member from each group has left the room, move any desks and chairs to one side to provide as much open space as possible (a chair or two may be left in the space serve as a "landmark"). Mark a spot on the floor with masking tape.

After collecting the directions from each group, go and get one of the people who have left the room, blindfold him/her and bring him/her to the doorway. Have a member of another group slowly read the directions from this person's group. Walk with the person so that he or she will not get hurt if they walk into something, but do not improve upon the directions given. When the directions are completed, remove the person's blindfold and measure and record how close he or she is to the mark.

Discuss with participants what is similar and what is different among groups. All groups will have measured distance in some manner such as, "Walk heel to toe" or, "Take normal steps." The differences between people's heel to toe distances or step sizes will be one of the reasons for error in the activity and set the stage for a discussion about standard distance measuring. Similarly, all groups will give some indication of direction such as, "Make a quarter turn to the right," or "Put your back against the wall so you are facing across the room." Differences in the interpretation of direction will also cause errors and highlight the need for a standard method for measuring direction. A discussion of the history and social implications of distance and direction measurement (How did Columbus or other early explorers find their way?) can illustrate how this topic may be integrated into the elementary curriculum.

III-A. Blindfold Navigation

1. Select a member of your group who is willing to be blindfolded and ask them to leave the room for 10 minutes.

2. Brainstorm with your group, methods of directing the blindfolded person from the doorway to the spot the workshop leader has marked on the floor. You may move about the room to plan your method. Write your directions on a piece of paper. Your directions are to be read by a member from another group so write clearly. No other directions or clarifications are allowed. Only what is on your paper will be told to your blindfolded teammate!

3. When the time is up, pass your directions to the workshop leader. As each group's directions are read, and the blindfolded person attempts to find the spot, jot down what the similarities and differences are between methods. Does one method seem better than another? Why?

This topic also integrates well with mathematics topics. Locating a spot on the floor is locating a point in two dimensional space. Locating the spot by walking parallel and perpendicular to the walls is the same as x and y graphing, which is an extension of graphing on number lines. Locating the point by giving a distance and direction is using polar coordinates and easily leads into a discussion of the difference between distance and displacement.

III. INQUIRE How Do We Get There from Here?

B. Measuring Distance and Direction

If the group has knowledge of what a meter and a centimeter are, no introduction is needed. If not, the leader should introduce these units using the meter stick. Leaders should also discuss the difference between an estimate and a guess. The purpose of this short activity is not to see if participants can define the meter and the centimeter but to give them an opportunity to "feel" them. Allow the participants to use either centimeters or meters and let them discover if one or another is better for a particular measurement, as well as how they can be converted to each other.

People often find longer distances harder to measure.

To measure direction one needs a reference point, and an instrument to measure an angle from a reference direction. Participants often suggest a compass. These can be used, but inside buildings they often are not reliable. Iron in the structure can cause them not to point to magnetic north. A simple solution is to use a protractor (the large "blackboard" type works well) and line it up with the walls of the room. If the floor of the room is made up of square tiles whose edges are parallel to the walls it is even easier. For the sake of discussion the direction to the front of the room can be given a name (it could even be called north) and all directions would be measured from this direction. The objective is for the participants to experience what is required to define direction. Do not be surprised if many of the teachers do not know how to read a compass or a protractor.

III-B. Measuring Distance and Direction

1. Using your knowledge of what a meter and a centimeter are, estimate the size of the following:

Height of the room _________
Length of the room _________
Width of your index finger _________
Your height _________

2. Using a meter stick check your estimates. How close were you? Were some distances easier than others?

Height of the room _________
Length of the room _________
Width of your index finger _________
Your height _________

3. How can we measure directions in this room? What equipment would be helpful?

III. INQUIRE How Do We Get There from Here?

B. Measuring Distance and Direction (cont.)

If time permits, you may want to mention the sport of "orienteering" and describe how the competitors make distance and direction measurements to find their way from one checkpoint to the next as they navigate an obstacle course. One or more participants may be familiar with orienteering and able to describe the experience.

Another interesting aside is to look at historical issues, such as the once daunting problem of measuring longitude. This was the topic of an excellent NOVA video, "Lost at Sea: The Search for Longitude", based upon the book of the same title by David Sobel. For script, viewing information, interactive online activities, and teacher resources, go to

www.pbs.org/wgbh/nova/

Because the solution to the longitude problem involved the use of time, this makes a nice tie-in to the activity that directly follows.

III-B. Measuring Distance and Direction

1. Using your knowledge of what a meter and a centimeter are, estimate the size of the following:

Height of the room _________
Length of the room _________
Width of your index finger _________
Your height _________

2. Using a meter stick check your estimates. How close were you? Were some distances easier than others?

Height of the room _________
Length of the room _________
Width of your index finger _________
Your height _________

3. How can we measure directions in this room? What equipment would be helpful?

III. INQUIRE How Do We Get There from Here?

C. Measuring Time

Select participants who will be willing to attempt to determine when a minute has elapsed (+ /- 5 sec.) without using any instruments. If there is a clock in the room be sure they cannot see it. Try this several times with different people. Few people can do this. Those that are successful often use their pulse or perhaps hum a tune of which they know the length (The Jeopardy tune is popular!). While all of the participants will know what a minute is, this short activity dramatically underscores the need for instruments to measure time and should initiate a discussion of what is required to define and measure time. The measurement of time has an interesting history and leaders should encourage teachers to explore it with their students.

Clock building is an activity that time in this workshop does not allow but would be worth mentioning as teachers may wish to do it with their students. Students may be given different sets of materials (the makings of a pendulum, a weight and spring, running water and a measuring cup, etc.) and asked to build a device to time a specific event. Consider providing teachers with articles or sources of information related to the history of timekeeping and the development, in historical order, of timekeeping devices and techniques such as : sundials, water clocks, observations of Jupiter's moons, hourglasses, mechanical(weight and spring driven) clocks, electronic watches, atomic "clocks", and satellite time transmittal.

III-C. Measuring Time

1. How long is a minute? Your workshop leader will ask for one or more persons to volunteer to tell, without using a watch or clock, when a minute has passed.

III. INQUIRE How Do We Get There from Here?

D. Make Sense

After a few minutes of small group discussion, direct a large group exchange of ideas. Use teachers' comments to gauge their understanding of the topic; address any areas that need clarification.

Ideas that participants should recognize include the following:

- **Distance, direction, and time must be defined, and a means of measuring them needs to be determined in order to accurately describe motion.**

III-D. Make Sense

1. One of the National Science Education Standards K-4 content standards states "The position of an object can be described by locating it relative to another object or the background." Discuss with your group what this standard means and come to a consensus you can share with the whole group. Also list any questions about the standard that you might have.

2. Get out your group's list of important "IDEAS ABOUT MOVING OBJECTS", and add any new ideas you have. Also check if there are any previous ideas that need to be modified or abandoned. Be prepared to share your group's ideas in a whole group discussion.

3. Get out your group's list of "QUESTIONS ABOUT MOVING OBJECTS". Have any of your groups questions been answered during these last activities? What new questions, if any, have arisen? Add these to your list.

III. INQUIRE How Do We Get There from Here?

E. Apply

Leaders should assign each group a different object in the room. If the total number of participants is large, groups could be assigned different starting points. You might mark the starting point by making an X with masking tape on the floor.

Leaders should circulate and answer questions raised without actually doing it for a group. Expect that some groups may require help because this may be their first experience in actually using a compass or protractor to measure direction.

III-E. Apply

1. Ask one of the members of your group to leave the room for five minutes. Using the methods learned in the last activity, determine the distance and direction from the doorway to the object your group was assigned. Write the directions on a piece of paper.

2. When your group member returns, have him or her attempt to find the object you were assigned using the written directions and the materials. Could they locate it?

IV. INQUIRE What Is the Meaning of Velocity?

GOAL:

To introduce the concepts of average speed, instantaneous speed and velocity.

OVERVIEW:

IV-A. What is Speed?
Each group is given a toy electric car that travels at a relatively constant speed. Using a meter stick and stopwatch, they are asked to design and conduct an experiment to measure the car's speed. The results are compared to determine which group's car was the fastest. As each group may have used a different definition of speed (the time to go a set distance, time/distance etc.) or different units, the comparison may be difficult. This leads to the necessity for a uniform definition of speed, and the opportunity to introduce it.

IV-B. Is the Speed Constant?
Participants are asked to determine the speed of a "pull back" type toy car that is released on a horizontal surface. Because these cars slow down as they travel, they can be used to illustrate the concept of average speed. By encouraging the participants to break the trip into smaller segments, the concept of instantaneous speed is explored. A discussion of average and instantaneous speed in the story "The Tortoise and the Hare" serves as a follow-up.

IV-C. Graphing Speed
Participants go outside or to a long corridor to measure the distance and time of people as they run a 25 meter course. Timers are stationed every 5 meters and measure the time from the beginning to their location. This produces a data table of distance and time that can be graphed. By having different people run different ways, (constantly slow, constantly fast, speeding up, slowing down) participants can compare the raw data, the graphs, and the speeds over different segments.

IV-D. Velocity Isn't Speed
This activity, which has teachers walk in different directions, emphasizes the difference between speed and velocity.

IV-E. Make Sense
What have we learned about velocity?

IV-F. Apply
Each group will be asked to find the average speed of a common motion (walking, running, biking, or car going by the building). The results of the groups will then be shared.

SCIENCE IDEAS

- An object's motion can be described by tracing and measuring its position over time. (NSES)
- Average speed is the distance traveled divided by the time to travel.
- Instantaneous speed is the average speed for infinitely small distances and times.
- Velocity is speed and direction.
- Average velocity is calculated by dividing displacement by elapsed time. It is a vector so it includes the direction of travel.

IV. INQUIRE What Is the Meaning of Velocity?

MATERIALS

IV-A. What Is Speed?
For each group:
- toy electric car that travels at a constant speed
- stopwatch
- meter sticks

IV-B. Is the Speed Constant?
For each group:
- "pull back" type toy car that slows down as it travels
- stopwatch
- meter sticks

IV-C. Graphing Speed
For the whole group:
- stopwatches
- meter sticks or metric tape measure
- graph paper

IV-D. Velocity isn't Speed
For each group:
- stopwatch
- meter stick or tape measure

IV-E. Make Sense
- no materials required for this activity

IV-F. Apply
For each group:
- stopwatch
- meter sticks or metric tape measure

IV. INQUIRE What Is the Meaning of Velocity?

A. What Is Speed?

Do not give directions to the groups, but let them devise their own methods. Different groups will most likely use different units, some may just give the time to go a certain distance or the distance traveled in a certain time. Some may divide the distance by the time while others might divide the time by the distance.

Because groups most likely used different units and methods, it will be difficult to compare. Do not be overly judgmental about one method versus another. Indeed runners often compare how fast they are by comparing times in a specific event (e.g.. the 4 minute mile) rather than their speed. The point to emphasize is that to make comparisons one has to have a common definition of speed and its units. The commonly accepted definition of speed is distance divided by time and the metric unit is the meter/ second.

$$\textit{Speed} = \frac{\textit{change in distance}}{\textit{change in time}} \quad \textit{or}$$

$$\textit{Speed} = \frac{?\ \textit{distance}}{?\ \textit{time}}$$

It is important for teachers to get a "feel" for speeds expressed in SI units. Lay several meter sticks across the floor and have teachers think about the time it takes to walk briskly past them. Have them similarly think about an ant crawling along a meter stick. To estimate speeds for cars and planes, tell teachers that a speed of 1 mile/hour is about the same as .5 meters/second (.447 m/s). Ask teachers to consider the reasonableness of this relationship in terms of what they know about human walking or jogging speeds.

IV-A. What Is Speed?

1. Given the materials supplied, devise a method of determining how fast your car is. Write down your method as well as the speed that you get.

2. Compare your results with the members of other groups. Whose car went the fastest? Is it easy to compare? Why or why not?

3. Calculate the speed of your car in meters/second. Now again compare your results with the members of other groups. Is it easier to compare?

4. Think about what would be a reasonable speed, expressed in SI units (meters/second), for :

- a person taking a brisk walk;
- a car on the interstate;
- the Concorde;

Reasonable answers:

Person (walking)	***1.0 meters/second***
Ant	***.02 meters/second***
Car	***30 meters/second***
Concorde (>1000 mi/hr)	***700 meters/second***

IV. INQUIRE What Is the Meaning of Velocity?

A. What Is Speed? (cont.)

This is a good point to introduce the difference between speed and velocity. While these two words are often used interchangeably, in physics there is an important distinction.

Speed is how fast something is going as defined in the above activity.

Velocity is the speed and direction of an object .

Example: An airplane pilot must know the speed and heading — or the velocity — of the plane.

Tell participants that the distinction between speed and velocity will become very important later as we explore how velocity is changed and what causes it to change.

IV-A. What Is Speed?

1. Given the materials supplied, devise a method of determining how fast your car is. Write down your method as well as the speed that you get.

2. Compare your results with the members of other groups. Whose car went the fastest? Is it easy to compare? Why or why not?

3. Calculate the speed of your car in meters/second. Now again compare your results with the members of other groups. Is it easier to compare?

4. Think about what would be a reasonable speed, expressed in SI units (meters/second), for :

- a person taking a brisk walk;
- a car on the interstate;
- the Concorde;

IV. INQUIRE What Is the Meaning of Velocity?

B. Is the Speed Constant?

Work with the "pull back" toy cars before the workshop to determine how far they go before it is obvious that they are slowing down for a given amount of pull. Have the participants measure for a long enough distance so that they will notice the slowing of the cars.

Once they notice the cars slow down, participants most often realize that the speed calculated by dividing the total distance by the total time is really the average speed. Relate this to trips they have taken in cars and how the average speed relates to different parts of the trip (at a stop light, on the highway, etc.)

By dividing the trip into two parts, participants will be able to determine the average speed in each part.

Have groups share their ideas. Most groups realize that by dividing the trip into smaller sections, (quarters, tenths etc.) and timing each section they will learn more about the motion. They may also realize that as the distances get smaller, so do the times, making it hard to measure with a stopwatch. From this discussion, develop the idea of instantaneous speed.

The distinction between average speed and instantaneous speed is an important one, but not an easy one to understand. This question helps focus on the distinction. While the tortoise won the race because he had the greatest average speed, the hare had the greatest instantaneous speed.

Relating this to other familiar examples of average and instantaneous quantities, such as food consumption during the course of the day (average calories over 24 hrs vs. consumption during lunch) or TV watching (average for the week vs. Saturday) can also be very helpful.

IV-B. Is the Speed Constant?

1. Determine the speed of the toy car.

2. What did the speed of the car do as it traveled along? What speed did you calculate?

3. How could you prove if it was going faster in the first or second half of the trip? Test out your method.

4. How could you find out even more about the speed in different sections of the trip? Come to a consensus in your group and be prepared to share your ideas with other groups.

5. Consider the children's story "The Tortoise and the Hare." Which animal had the greatest speed? Be prepared to defend your answer.

Before proceeding to the next activity, make sure that the teachers are comfortable not only with the difference in the definitions of average and instantaneous speeds, but also with the method by which each can be measured.

IV. INQUIRE What Is the Meaning of Velocity?

C. Graphing Speed

It is best if this activity is done in small groups; however, because of the large number of stopwatches required, you may find it necessary to do it as a whole group.

This lab is best done outside or in a large gym or similar space. Arrange the groups so that each one is large enough to complete the task. Assign a different running pattern to each group. Go at a slow but constant speed; go at a fast constant speed; start slow and speed up; start fast and gradually slow down, etc.

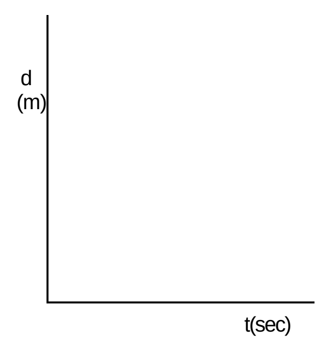
Have the groups share their results with the whole group. Ask participants to consider what the slope and general shape of each graph reveals about the motion. If the technology is available, it is very helpful to create an overhead transparency of each group's graph. By using the same scale they can be overlapped and the differences in the graphs and their corresponding motions can be clearly seen. Once participants are clear about how the graphs describe motion, it may be a good time to show how the same data graphed at different scales may look different but are really the same.

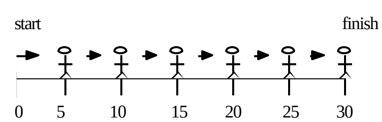
It might be useful to point out that only speed, not velocity, was considered in this activity because direction was not important. All of the motions were in a straight line in a single (and arbitrary) direction.

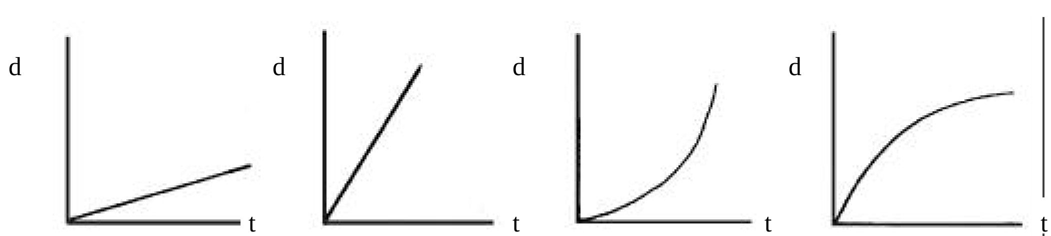
IV-C. Graphing Speed

1. Set up a straight 40 meter course. Every 5 meters, station a person with a stopwatch. Select a member of your group to be the runner who will travel the course in the manner described by the workshop leader. Have a person serve as a starter by standing near the beginning with his or her hand up. The lowering of the starter's hand is the signal for the runner to begin and for all of the timers to start their watches. As the runner passes each timer, that timer should stop his or her watch. One person should serve as a recorder and collect all of the data and make a table of distance and time.

2. Create a graph of your data with distance on the vertical axis and time on the horizontal using the scale described by the workshop leader. Discuss with your group how this graph describes the motion of your runner and be prepared to share it with the whole group.







slow constant speed | fast constant speed | speeding up | slowing down

IV. INQUIRE What Is the Meaning of Velocity?

D. Velocity Isn't Speed

Be sure participants have discussed the distinction between displacement and distance traveled. You might want to discuss it before beginning this activity.

The values will be the same as for the speeds, but they have opposite directions (right vs. left or north vs. south, for example). These answers must have directions to be considered velocities.

No. The velocity is more important. If the velocity is wrong, you might be going the wrong way, or you might be driving onto the sidewalk.

No. Your velocity changes as you turn corners and as you go over hills.

Velocity and speed have different definitions and may serve different purposes. Unlike speed, velocity requires a direction in order to be fully expressed.

Review the terms: **distance traveled, displacement, position, average speed, average velocity**.

IV-D. Velocity Is not Speed

1. Measure a straight-line distance of two or three meters that you can walk. Mark the ends, calling one end A and the other end B.

2. Time someone walking from A to B. Calculate the average speed for the walk. Show your calculations below:

Distance: ____________

Time : ____________

Avg. Speed: ____________

3. Have the same person walk back from B to A. Try for the same speed. Calculate the average speed for the walk. Show your calculations below:

Distance: ____________

Time : ____________

Avg. Speed: ____________

4. When you walk from A to B you might have the same speed as when you walk from B to A, but you are doing something quite different. When the direction of travel is different, the result is different. When we talk about how fast something moves, we sometimes need to consider the direction of travel. When the direction doesn't matter we use the term speed. When the direction does matter we use the term velocity.

What were the velocities for the two walks above?

Average velocity walking from A to B: _______________

Average velocity walking from B to A: _______________

5. When you are driving a car on a one-way street, is your speed as important as your velocity? Why?

6. Driving on the freeway with the cruise control set, does your velocity stay constant along with your speed? Explain.

EXTENSION: *Have participants suggest velocities for a walker that will have significantly different results, like walking into a wall, instead of away from a wall.*

IV. INQUIRE What Is the Meaning of Velocity?

E. Make Sense

Allow groups to share their ideas about the standard. Make sure that participants can describe how distance, direction, and time are each essential to the description of motion.

Ideas that participants should recognize include the following:

- **Average speed is the distance traveled divided by the time to travel.**
- **Instantaneous speed is the average speed for infinitely small distances and times.**
- **Velocity is speed and direction.**

IV-E. Make Sense

1. One of the National Science Education Standards K-4 content standards states "An object's motion can be described by tracing and measuring its position over time." Discuss with your group what this standard means and come to a consensus you can share with the whole group. Also list any questions about the standard that you might have.

2. Get out your group's list of important ideas about moving objects, and add any new ideas you have. Also check if there are any previous ideas that need to be modified or abandoned. Be prepared to share your group's ideas in a whole group discussion.

3. Get out your group's list of questions about moving objects. Have any of your group's questions been answered during these last activities? What new questions, if any, have arisen? Add these to your list.

IV. INQUIRE What Is the Meaning of Velocity?

F. Apply

The purpose of this activity is to assure that the participants can apply on their own what they have learned in this section. By careful selection of items measured, they can begin to get a feel for speeds expressed in meters/second. Cars going along the street, a person on a bike, a kicked soccer ball and the like make excellent examples.

When groups are finished, have them share their procedures and results. Prompt teachers to consider the reasonableness of each set of results.

Participants should use techniques introduced in the previous Inquire.

***EXTENSION**: If the workshop setting allows, you might show participants how one can quickly estimate the speed of an object moving past fixed reference objects that are equally spaced such as telephone poles, fence posts, sidewalk cracks, yardline markers on a football field, etc.*

IV-F. Apply

1. Using the equipment supplied, find the average speed of the object assigned to your group. Be prepared to share your results with the whole group. Calculate your speeds in meters/second so the results can be easily compared.

2. What is the average velocity of the object?

V. INQUIRE How Many Ways Can Velocity Be Changed?

GOAL:

To introduce the concept of acceleration, including the rate of increasing speed, decreasing speed, or changing direction.

OVERVIEW:

Participants explore acceleration, starting with "feeling" acceleration in a straight line, then learning how to calculate it. They then explore changing direction as a form of acceleration.

V-A. Feeling Acceleration
A bowling ball is placed on the floor and a participant is asked to tap on the side of it with a croquet mallet at a constant rate. As the ball picks up speed, the participant will have to move faster and faster to keep up with it, graphically illustrating the concept of acceleration.

V-B. Measuring Acceleration
The concept of calculating acceleration is developed using a zip line (weight on a pulley that travels across the room on an inclined string).

V-C. Three Ways to Change Velocity
The participants discover how to change velocity by increasing speed, decreasing speed, or turning.

V-D. Make Sense
What have we learned about acceleration?

V-E. Apply
Participants calculate the acceleration of air pucks as they travel up or down an inclined surface.

SCIENCE IDEAS

- Velocity can be changed by increasing or decreasing the speed and/or changing the direction of the motion.
- The rate at which velocity changes is called acceleration

MATERIALS:

V-A. Feeling Acceleration
For each group:

- bowling ball
- croquet mallet
- chair

V-B. Measuring Acceleration
For each group:

- string (cotton works well; avoid string that stretches easily)
- small pulley
- object of approximately 50g to hang on pulley
- meter stick
- stopwatch

V-C. Three Ways to Change Velocity
For each group:

- balloon
- air puck
- table with smooth level top

V-D. Make Sense

- no materials required for this activity

V-E. Apply
For each group:

- air puck
- table with smooth level top
- material to raise one end of the table
- tape
- thread

V. INQUIRE How Many Ways Can Velocity Be Changed?

A. Feeling Acceleration

Inform participants that they will now revisit parts of the earlier bowling ball activity, but this time think about if and how the velocity of the ball is changing. As before, the activity should be performed on a smooth, hard, level surface.

As the ball is tapped, it accelerates, causing the participants to run faster and faster to continue tapping it.

Participants should note that the ball must be tapped in a direction toward the center of the circle.

When participants have finished all three parts of the activity, hold a round-up discussion. Review the definition of velocity, reinforcing the idea that velocity is speed and direction. Ask participants to describe the specific ways in which the velocity of the bowling ball changed in light of this definition.

The term "acceleration" may come up during this discussion. If so, this would be an appropriate time to define acceleration, both in words and mathematically. (see next page).

It is premature at this point to discuss the nature and direction of the forces that produced the observed changes in velocity. Expect that some participants will want either an immediate explanation for certain observations (such as the direction the ball must be hit to produce circular motion) or a validation of their ideas about how forces cause changes in velocity. Use your best judgment as to how to handle this situation. One approach is to capitalize on this as an opportunity to discuss the nature of science and to commend the participants for beginning to behave like real scientists in raising their own questions and/or trying to make sense of their observations.

V-A. Feeling Acceleration

1. Place the bowling ball on the floor. Begin tapping it and continue tapping at a constant rate (a little faster than about one tap per second is good) in the same direction. What do you have to do to keep tapping the ball? What is the ball doing?

2. If the ball were moving and you wished to stop it by tapping, which side would you tap? Try it.

3. How do you have to tap the ball to get it to move in a circle? When the ball moves in a circle, is its velocity constant or does it change?

In this regard, suggest participants note question(s) on their LIST OF QUESTIONS ABOUT MOVING OBJECTS and jot down any initial ideas they may have. As the workshop progresses, they will be able to use their bowling ball observations and other evidence to formulate their own ideas.

V. INQUIRE How Many Ways Can Velocity Be Changed?

B. Measuring Acceleration

Advance Preparation : *Set up the zip line and let participants observe the pulley accelerating across the room. The ideal angle of the zip line depends on many factors such as the weight of the pulley and object, the friction in the system, and how much the string sags. If the angle is too steep, the speeds are too fast to be measured with a stopwatch and meter stick. If the angle is too shallow, the pulley will not constantly accelerate. In tests, a set up that worked well included a small lab pulley with a hooked 50g mass attached, set on a tight cotton string that dropped .4m in a horizontal distance of 6m.*

Expect that some groups will define acceleration only in terms of increasing speed. Draw out the idea that acceleration involves any change in velocity — speeding up, slowing down, and/or changing direction. Emphasize that acceleration is NOT defined simply as "change in velocity", but is a way of describing how quickly velocity changes. Give some examples.

With the careful use of focusing questions, groups should realize that measuring acceleration requires measuring how much speed changes and how long it takes to change. As the discussion unfolds, write the definition of acceleration first in words and finally in equation form :

$$acceleration = \frac{+\ velocity}{+\ time}$$

The idea here is not to tell the participants what to do, but rather to draw the ideas out of them. Because of the previous activities on average and instantaneous speeds, most groups will settle on the idea of measuring out a short distance at the beginning and the end and timing the pulley as it crosses those distances. They will also time how long it takes the pulley to make this change in speed. In the test set-up described above, 1m intervals were laid out on the string with a marker pen at the beginning and from 5m to 6m.

V-B. Measuring Acceleration

1. Brainstorm in your group what you think acceleration is and how it can be measured. Be prepared to share your ideas with the whole group.

2. Design a method to determine the acceleration of the pulley on the zip line, and again be prepared to share it with the whole group.

3. Is the acceleration of the pulley uniform (constant) across the zip line? How could you find out?

Some groups may raise the question as to whether the time to change the speed should be measured from the beginning or end of the one-meter intervals. As the acceleration is almost constant, measuring from the middle of each interval will be the best (marking these points with a different color pen is helpful).

V. INQUIRE How Many Ways Can Velocity Be Changed?

B. Measuring Acceleration (cont.)

Once the procedure has been determined, run the experiment and determine the acceleration.

After the results are calculated, the opportunity will arise to discuss units of acceleration. To clarify these, use examples of everyday objects (such as the ones measured in the previous Inquire) and use round numbers.

EXAMPLES:

An automobile increases its speed by 15 mi/hr each second:

$$a = \frac{+\ v}{+\ t} = \frac{15\ mi/hr}{1s} = 15\ mi/hr/s$$

A toy car starts at rest and achieves a speed of 1m/s in 2s:

$$a = \frac{+\ v}{+\ t} = \frac{1\ m/s}{2s} = .5\ m/s/s = .5\ m/s^2$$

An object freely falling toward the ground (ignoring air resistance) increases its speed by 10 m/s each second of fall:

$$a = \frac{+\ v}{+\ t} = \frac{10\ m/s}{1s} = 10\ m/s^2$$

V-B. Measuring Acceleration

1. Brainstorm in your group what you think acceleration is and how it can be measured. Be prepared to share your ideas with the whole group.

2. Design a method to determine the acceleration of the pulley on the zip line, and again be prepared to share it with the whole group.

3. Is the acceleration of the pulley uniform (constant) across the zip line? How could you find out?

Draw out the idea that one could find the acceleration between two different one-meter intervals along the zip line, and see if it is the same as, or different from before. Discuss the meaning of the terms : uniform acceleration, average acceleration, and instantaneous acceleration.

Now that participants are more comfortable with a definition of acceleration, throw the pulley up the zip line and discuss slowing down as a type of acceleration. Use the equation to show that it will still work, and that the units will still be the same.

V. INQUIRE How Many Ways Can Velocity Be Changed?

C. Three Ways to Change Velocity

Advance Preparation : *Workshop leaders will have to demonstrate how to use the air pucks. If possible, it can be helpful to level the tables before this activity. This can be done by placing the inflated puck on the center of the table and putting cardboard or similar material under the legs until the puck remains stationary. As most tables are not perfectly flat, this may be difficult to completely accomplish, but getting it close will suffice.*

Participants should notice that, after the puck is tapped, it travels in a straight line at a constant speed (constant velocity).

The instructions may need some clarification by the workshop leader. The idea is not to have them focus on methods of getting the velocity to change (such as by pushing, pulling, hitting etc.) but rather to focus on what about the velocity is changing (increasing speed, decreasing speed, or changing direction). This activity is designed to focus the attention of the participants on the idea of changing direction as a type of acceleration. While it is beyond the scope of this workshop to derive the vector version of the acceleration equation, participants should be made aware that turning, even while maintaining a constant speed, is a type of acceleration (and, as shall be demonstrated in a future Inquire, requires an unbalanced force).

V-C. Three Ways to Change Velocity

1. After inflating the balloon, place the puck on the table and tap it. How would you describe the motion after it is tapped?	2. If constant velocity means going in a straight line at a constant speed, show three ways it can be changed.

With some encouragement, participants will discover that velocity can be changed by increasing or decreasing speed, or changing direction. Some will also begin to see that it takes a force to do this (pulling the puck with a string, tilting the table, etc.). Workshop leaders should avoid the urge to discuss Newton's Laws at this point and just note the participants' observations and defer the discussion until the activities of the next Inquire.

V. INQUIRE How Many Ways Can Velocity Be Changed?

D. Make Sense

Give teachers ample time to discuss and formulate answers to these questions.
Answers: 1a. Volkswagen
1b. Porsche
2. choice c
3. an object moving on a curved path or circle at a constant speed.

Teachers need time to sort out the new ideas that have been developed during this Inquire. Be alert to any mis-conceptions that arise and take time to carefully address these. You may find it necessary to conduct additional activities, demonstrations, or discussions before proceeding to the next Inquire.

Encourage groups to share any changes or additions they have made to their lists.

Summarize all of the groups' ideas by generating a list of unanimous ideas. This list should include the following:

- **Velocity can change by increasing or decreasing speed and/or changing the direction of the motion.**
- **How quickly velocity changes is called acceleration.**

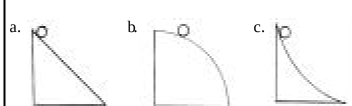
V-D. Make Sense

1. It takes 5 seconds for a Volkswagen traveling along a straight and level road to increase its speed from 30 m/sec to 40 m/sec. It takes 2 seconds for a Porsche traveling on the same road to increase its speed from 10 m/sec to 30 m/sec.

a) Which car has the greatest acceleration?

b) Which car has the greatest final speed?

2. Which hill will the ball roll down with increasing speed and decreasing acceleration?



3. Can you think of an object that : accelerates while moving at a constant speed?

4. Get out your group's list of QUESTIONS ABOUT MOVING OBJECTS. Have any of your group's questions been answered during these last activities? What new questions, if any, have arisen? Add these to your list.

5. Get out your group's list of IDEAS ABOUT MOVING OBJECTS, and add any new ideas you have. Also check if there are any previous ideas that need to be modified or abandoned. Be prepared to share your group's ideas in a whole group discussion.

Be sure to continually re-emphasize that acceleration is not simply "changing velocity", but rather is the rate at which velocity changes.

V. INQUIRE How Many Ways Can Velocity Be Changed?

E. Apply

NOTE: *If you have trouble getting this activity to work with the balloon pucks, you can substitute free-wheeling, metal die-cast toy cars such as Hot Wheels®. If the cars tend to veer off at an angle, tape a meter stick to the table surface and let the cars roll alongside the meter stick.*

As in the activity with the zip line, the angle of the incline is important. If it is too steep, it is difficult to measure the initial and final speeds without equipment such as light gates. In testing, using a rise of 1cm on one side of a student desk that was 1.22m (approx. 4ft.) long worked well when intervals of 10cm were used near the beginning and end.

When completed, have groups share their method and results.

V-E. Apply

1. Incline the table as described by the workshop leader. Determine the acceleration of the puck as it travels down the incline. Be prepared to discuss your method with the whole group.

2. Practice pushing the puck so that it travels up the incline stopping near the top. Determine the acceleration (deceleration) as it travels in this direction.

VI. INQUIRE What Does It Take to Make Things Accelerate?

GOAL:

To introduce force and its relationship to acceleration.

OVERVIEW:

The Inquire begins with an investigation into the causes of acceleration. The concept of force is then developed, including its origin and measurement. The effects of balanced and unbalanced forces are explored and Newton's first and second laws are introduced and applied.

VI-A. What Causes Acceleration?
The activity used in the Elicit/Explore (moving a bowling ball in a figure eight pattern using a croquet mallet) is redone. This time the participants are asked to focus their attention on when the velocity is constant and when it is changing. What does it take to get it going? How about to keep it going? ...to turn?...to stop? Participants are then asked to reconsider the activities in the last Inquire and determine what caused the acceleration.

VI-B. What is Force?
Participants brainstorm examples of forces in everyday life. Participants share their ideas about the relationship between force and motion. Gravity and friction, two forces that affect almost all everyday motions, are demonstrated and discussed. [NOTE: The topic of this workshop module is moving objects. The focus should be on description of motion. Forces should only be introduced to the extent necessary to help participants distinguish between constant velocity and accelerated motion.] The Newton is introduced as the unit of force.

VI-C. Balanced and Unbalanced Forces
The workshop leader uses a roller skate attached to a spring scale to discuss and demonstrate the idea that an object is at rest or moving with a constant velocity when the forces on it are balanced, and an object accelerates when the forces on it are unbalanced.

VI-D. Make Sense
What have we learned about forces and acceleration?

VI-E. Apply
Participants build a marble "roller coaster" containing hills, valleys, straight-aways, and turns using flexible, half-round track. They describe the net force and the resulting type of motion in each section of the track.

SCIENCE IDEAS

- The position and motion of an object can be changed by pushing or pulling.
- The size of the change is related to the strength of the push or pull. (NSES)
- A force is a push or a pull.
- If the net force on an object is zero, its velocity is constant.
- If the net force on an object is not zero, the object will accelerate.

VI. INQUIRE What Does It Take to Make Things Accelerate?

MATERIALS:

VI-A. What Causes Acceleration?
For each group:
- bowling ball
- croquet mallet
- 2 chairs

VI-B. What Is Force?
For each group:
- aluminum foil
- pencil
- 30-cm length of string
- spring scales of various ranges calibrated in Newtons

VI-C. Balanced and Unbalanced Forces
For each group:
- board (at least 3 feet long)
- books (to make incline plane)
- roller skate
- spring scale

VI-D. Make Sense
- no materials required for this activity

VI-E. Apply
For each group:
- marble
- several sections of half round flexible foam pipe insulation
- tape or other method of attaching the sections of insulation
- chairs, books or other materials to form the insulation into hills, etc.

VI. INQUIRE What Does It Take to Make Things Accelerate?

A. What Causes Acceleration?

Due to friction, this should not be done on a rug, but rather on a level, smooth, hard-surfaced floor. On this type of floor, the friction will be small enough not to be a factor. If a room with a rug is available, it could be re-done on the rug near the end of the activity and the causes of the differences discussed.

Velocity changes when the ball speeds up, turns around the chairs, and/or slows down. During the straight parts of the trip the velocity is constant.

***Note:** Some groups may continue to hit the ball during the straight parts of the trip to speed it up and consequently will not notice constant velocity. Try encouraging these groups to get the ball around the course with the minimum number of taps. They will soon discover that they don't have to hit it during the straight parts of the trip and will observe the constant velocity.*

Unbalanced force (tapping)

An unbalanced force (tapping) was not required.

Observe to see if groups remember that velocity can be changed three ways. Reinforce the idea that any of these constitute acceleration. If they overlook this, focus their attention on all three ways the puck accelerated.

Gravity

VI-A. What Causes Acceleration?

1. Set up and re-do the activity of tapping the bowling ball so that it travels in a figure eight pattern around two chairs and stops (there is no need to time it again). Describe when during the trip the velocity is changing and when it is constant. Be sure to focus on the three ways velocity can change.

2. Focus on the parts of the trip when the velocity changed. What was causing the change?

3. Focus on the parts of the trip when the velocity was constant. What was different from when it was accelerating?

4. Look at your results from the activity in the last INQUIRE using the air puck. When the puck accelerated, what caused it? What was different when the velocity was constant?

5. In the activity with the zip line, what caused the acceleration?

VI. INQUIRE What Does It Take to Make Things Accelerate?

B. What Is Force?

After 5-10 minutes, stop and hold a whole-group discussion. Draw out the definition (which most elementary teachers are familiar with) that a force is "a push or a pull." Post as many of the different examples of forces on the board as possible.

This elicitation of participants' ideas is extremely important because of the prevalence of misconceptions about the relationships between force and motion. Give teachers plenty of time to think about and discuss ideas in their small groups. Bring groups together to share and compare ideas. This exchange can provide fodder for further discussion. If certain issues arise and teachers want to test their ideas, try to be flexible and allow this to occur if the necessary materials are available.

VI-B. What Is Force?

1. Discuss in your group the meaning of the word "force". Brainstorm as many different examples of forces as you can think of. In what way(s) are all of your examples alike? Can you group the examples into categories? Be prepared to share your thoughts with the whole group.

2. Does force imply motion? Does motion imply force? Discuss ideas among your group.

3. How are forces measured?

VI. INQUIRE What Does It Take to Make Things Accelerate?

B. What Is Force? (cont.)

The discussion, and any subsequent investigations, can lead to a consideration of two very important forces that affect almost every example of motion in the everyday world: gravity *and* friction. *Discuss each of these to the extent necessary for teachers to perform the remainder of the workshop activities.*

GRAVITY *— Generate a discussion by asking teachers to voluntarily relate what they already know about gravity. As ideas are brought forth, write them on chart paper or on an overhead for all to see and discuss. Bring out the idea that all objects on or near the surface of the earth are attracted to the earth. This attractive force is called gravity. Gravity continually acts on all objects whether they are moving or not. Discuss that what is commonly called weight is actually the force of gravity. Using a marble and a ramp, discuss how it is gravity that pulls objects down inclines, and that the steeper the incline the greater the pull. The difference between weight and inertia (mass) is conceptually a difficult one to grasp. A later Inquire deals with this important difference. Workshop leaders may find it best to make note of any participant questions about this and to defer them until they can be addressed by the later activities.*

FRICTION *— Ask participants to similarly share what they know about friction, and post these ideas for further discussion and refinement. Discuss how friction is present whenever two surfaces rub across one another, that friction is a force that always acts in a direction to oppose motion, and that it is due in large part to irregularities in the two surfaces that are in contact. Develop the idea that the amount of friction present depends on the nature of the two surfaces rubbing past one another and how much they are pressed together. Discuss how friction is also present whenever an object moves through a fluid such as air (in which case it is called air resistance or drag). Finally, emphasize that, while friction always acts in a direction opposite to motion, it is not always an undesirable force. Discuss how critically important friction is in getting objects to start moving, and in helping objects to bring moving objects to rest. Give examples of both of these.*

VI. INQUIRE What Does It Take to Make Things Accelerate?

B. What Is Force? (cont.)

Culminate the discussion by attempting to reach closure on the main questions about force and motion. This sets the stage for the next activity on balanced and unbalanced forces.

To introduce the Newton as the unit of force, pass out Newton weights and let teachers get a feel for what a Newton is. Since a Newton is a little less than a quarter of a pound, one might discuss a Newton as roughly equivalent to a cooked quarter pounder (a Newton burger?). Passing out spring scales of various ranges calibrated in Newton's, and having participants pull on them, is also helpful.

Show participants how they can read the force of gravity pulling on an object (or the object's weight) by hanging the object from a spring scale.

Demonstrate how friction can be measured by pulling an object across a horizontal surface at a constant speed by means of an attached, horizontally oriented, spring scale.

OPTIONAL: Discuss the difference between static friction and sliding friction.

VI-B. What Is Force?

1. Discuss in your group the meaning of the word "force". Brainstorm as many different examples of forces as you can think of. In what way(s) are all of your examples alike? Can you group the examples into categories? Be prepared to share your thoughts with the whole group.

2. Does force imply motion? Does motion imply force? Discuss ideas among your group.

3. How are forces measured?

VI. INQUIRE What Does It Take to Make Things Accelerate?

C. Balanced and Unbalanced Forces

Management Suggestion: Weight can be added to the skate so that it registers at the high end of the spring scale. Also, this activity has been broken into three sections so that a whole-group discussion can take place after each section to clarify concepts before moving on.

Help the groups establish that gravity is pulling the skate down while the spring scale is pulling up.

Most groups will say it is stopped. Point out that "stopped" is a particular case of constant velocity.

The weight of the skate would be the unbalanced force. The velocity would change by increasing. If groups don't realize this, discuss dropping a marble from increasing heights. It lands harder from higher heights (ignoring air friction) because it is going faster.

Bring participants together for a whole group discussion at this point to clarify the responses to the questions in this section.

VI-C. Balanced and Unbalanced Forces

SECTION I

1. Lift the skate with the spring scale to determine its weight. Draw a diagram of the skate and all of the forces on it (using arrows to represent the forces). Is there an unbalanced force on the skate?

2. How would you describe the velocity of the skate while it is hanging on the spring scale?

3. Draw a diagram of the forces on the skate if it were to be released from the spring scale. Is there an unbalanced force? What would happen to the velocity of the skate?

VI. INQUIRE What Does It Take to Make Things Accelerate?

C. Balanced and Unbalanced Forces (cont.)

Participants may have difficulty drawing all of the forces involved. Help them refine their diagrams.

As in Section I, it is stopped which is a constant velocity.

The force down the plane which was being balanced by the spring scale is now the unbalanced force. Because of the past activities with the zip line and air puck, participants should realize that the skate will accelerate.

Bring participants together for a whole group discussion at this point to clarify the responses to the questions in this section.

VI-C. Balanced and Unbalanced Forces

SECTION II

1. Make an inclined plane from one or two books and the board provided. Place the skate on the incline and hold it from rolling down by holding the spring scale parallel to the ramp. How does the force caused by the spring scale compare to the total weight of the skate? Draw a diagram showing all of the forces on the skate. Is there an unbalanced force on the skate?

2. How would you describe the velocity of the skate while it is being held by the spring scale?

3. Draw a diagram of the forces on the skate if it were to be released from the spring scale. Is there an unbalanced force? What would happen to the velocity of the skate? Try it.

VI. INQUIRE What Does It Take to Make Things Accelerate?

C. Balanced and Unbalanced Forces (cont.)

The diagram should be similar to the last one, but with a larger force down the plane.

Stopped (constant velocity).

Bring participants together for a whole group discussion at this point to clarify the responses to the questions in this section.

VI-C. Balanced and Unbalanced Forces

SECTION III

1. Increase the angle of the incline by adding more books. Again, place the skate on the incline and stop it from rolling down by holding the spring scale parallel to the ramp. How does the force caused by the spring scale compare to what it was on the shallower ramp? Draw another diagram showing all of the forces on the skate. Is there an unbalanced force on the skate?

2. How would you describe the velocity of the skate while it is being held by the spring scale?

3. What would happen to the velocity of the skate if it was released from the spring scale this time? Try it.

VI. INQUIRE What Does It Take to Make Things Accelerate?

C. Balanced and Unbalanced Forces (cont.)

No unbalanced force — velocity constant at zero.

The responses will vary depending on how much friction is acting on the skate. If the skate is relatively frictionless, most participants will realize that there is no unbalanced forces and the velocity is constant (but not zero this time). If the velocity is clearly slowing down, it will raise the opportunity to discuss friction as the unbalanced force slowing it down. Relate this to previous activities with the air pucks.

Bring participants together for a whole group discussion at this point to summarize the conclusions drawn from all of the sections of this activity.

Ideas that participants should recognize :

- *If the net force on an object is zero, its velocity is constant.*
- *If the net force on an object is not zero, the object will accelerate.*

VI-C. Balanced and Unbalanced Forces

SECTION IV

1. Place the skate on a smooth level table. Draw a diagram showing all of the forces on the skate. Is there an unbalanced force on the skate? How would you describe the velocity of the skate?	2. Push the skate to get it going and then release it. Draw a diagram showing all of the forces on the skate after you released it. Is there an unbalanced force on the skate? How would you describe the velocity of the skate now?

VI. INQUIRE What Does It Take to Make Things Accelerate?

D. Make Sense

Ideas that participants should recognize include the following:

A force is a push or a pull.

If the net force on an object is zero, its velocity is constant.

If the net force on an object is not zero, the object will accelerate.

When a force acts on an object in the direction of its motion, the object's speed will increase.

When a force acts on an object in a direction opposite to the direction of motion, the object's speed will decrease.

When a force acts on an object at a right angle to the direction of its motion, the object will change its direction.

When a force acts on an object at any other angle to the direction of motion, the object will change its speed and direction.

The direction of the force acting on an object moving in a circle is toward the center of the circle.

VI-D. Make Sense

1. One of the National Science Education Standards K-4 content standards states "The position and motion of objects can be changed by pushing or pulling. The size of the change is related to the size of the push or pull." Discuss with your group what this standard means and come to a consensus you can share with the whole group. Also list any questions about the standard that you might have.

2. Get out your group's list of important ideas about moving objects, and add any new ideas you have. Also check if there are any previous ideas that need to be modified or abandoned. Be prepared to share your group's ideas in a whole group discussion.

3. Get out your group's list of "QUESTIONS ABOUT MOVING OBJECTS". Have any of your group's questions been answered during these last activities? What new questions, if any, have arisen? Add these to your list.

VI. INQUIRE What Does It Take to Make Things Accelerate?

E. Apply

Management suggestion: When purchasing foam pipe insulation, choose the type that does not flatten out when bent into curves. Also, clear plastic tubes that are sold as protectors for 4-ft florescent lamps can be cut into short pieces and work very well for joining the sections of insulation. (Buy the size that fits snugly inside).

Have participants share their conclusions with the whole group. Participants should be able to relate the ideas of force and motion introduced in this Inquire to each section of the trip. Use this discussion as an opportunity to clarify these concepts.

On sections of the track where forces are unbalanced, have participants describe the relative size and direction of the net force.

VI-E. Apply

1. Using the materials provided, build and test a "roller coaster" for your marble. Try to include as many hills, turns, straight-always, and loops as possible.

2. Draw a diagram for your coaster and tell if the forces on the marble are balanced or unbalanced at each section of the trip. If there is an unbalanced force in a section, indicate the direction of the force. Be sure to give evidence for all of your conclusions.

VII. INQUIRE Are Some Things Harder to Accelerate than Others?

GOAL:

To introduce the concept of mass (inertia) and the difference between mass and weight.

OVERVIEW:

VII-A. Inertia
Objects of varying mass will be hung from the ceiling. Participants will attempt to accelerate them by blowing through a straw leading to a discussion of mass vs. weight.

VII-B. Make Sense
What have we learned about forces and acceleration and inertia? Participants will be given a brief description of the notion of the causes of motion in Aristotelian physics. They will be asked to refute these notions using what they have learned in the workshop.

VII-C. Apply
Participants will be asked to predict the how the initial Explore/Elicit activity would feel if the bowling ball was replaced by a soccer ball. They will then check their predictions by playing it with a soccer ball.

SCIENCE IDEAS

- Mass (inertia) is the resistance to acceleration.
- Mass is not a force.

MATERIALS:

VII-A. Inertia
For each group:
- straws

Materials for the workshop leader:
- film cans
- sand
- string
- scissors

VII-B. Make Sense
- no materials required for this activity

VII-C. Apply
For each group:
- soccer ball
- croquet mallet
- 2 chairs

VII. INQUIRE Are Some Things Harder to Accelerate than Others?

A. Inertia

Management suggestion: The workshop leader should hang the film cans (one empty, one filled with sand) for each group so that they do not handle them. They can be hung from the ceiling, the door jams, ring stands, etc.

Groups will easily determine that one is harder to move than the other. When asked what to call the property of resistance to acceleration, some may say inertia or mass, but many may confuse it with weight. (Due to the scope of this workshop, mass will be discussed only in terms of inertial mass and not gravitational mass.) This confusion is common because on earth (or any other planet) the more mass something has the more weight it will have. When objects are moved far away from a planet where the gravitational field, and hence the weights, are essentially zero, then "weightless" objects still are seen to have differences in mass. The demonstration attempts to illustrate this. Note that the weight of the can is balanced out by the upward pull of the string (relate this to the concepts in the last ***Inquire****), yet there is still a difference in how they react to the force from the puff of air.*

Workshop leaders should point out that since weight is the force of gravity then the unit of weight is the unit of force -- the Newton. They should also point out that the unit of mass is the kilogram.

VII-A. Inertia

1. Do not touch the hanging film cans (with your hands or the straw). Try to determine if one of them is more difficult to move by blowing on them through the straw. Are they the same or are they different? If different, what would you call the property that makes them different?

2. OPTIONAL: Observe as your workshop leader performs one or more demonstrations. Write down any new ideas that you develop about moving objects as a result of these demonstrations.

Workshop leaders must be prepared to discuss this important and conceptually difficult topic in as clear and non-threatening a way as possible. Participants often have questions such as, "If gravity holds the moon in orbit, how come astronauts are weightless when orbiting the earth?" Only by being properly prepared can workshop leaders deal with these questions.

VII. INQUIRE Are Some Things Harder to Accelerate than Others?

Follow-Up

Conduct one to three favorite inertia demonstrations. While any demonstrations of inertia may be used, most desirable are demonstrations that show that objects with greater mass (greater inertia) are more difficult to accelerate than those of lesser mass. Two suggested demonstrations follow :

Egg Drop : *Set a large beaker of water near the edge of the demonstration table. Place an aluminum pie pan on top of the beaker and stand a cardboard toilet paper tube in the center of the pie pan. Carefully balance a raw egg on the top of the tube. Stand a broom beside the table, step on the straw end, cock the handle back and aim it directly at the lip of the pie pan. Let go and watch the pie pan and cardboard tube fly outward as the egg drops into the beaker of water. Ask participants to explain why the cardboard tube flew outward and the egg did not. Discuss how the egg, because of its relatively larger mass (inertia), is harder to accelerate than the cardboard tube.*

Tablecloth Jerk : *Place a colorful gift-wrap paper so that it covers about 30-40 cm of one end of a table and the remainder of the roll hangs off the end. Set a plate, knife, fork, bowl, glass of water, etc. on the gift wrap covered end of the table. With both hands, grab a hold of the roll hanging from the end of the table and, with a quick and continuous downward motion, jerk the paper tablecloth out from under the dishes. Ask participants to note what item(s), if any, move when the paper tablecloth is jerked away. Draw out the idea that the items with smaller mass (such as the fork) are easier to begin moving, or to accelerate. Point out that adding water to the glass actually makes the trick easier because of the increased mass (inertia). Discuss the importance of using dishes with smooth bottoms in order to reduce the amount of friction.*

VII. INQUIRE Are Some Things Harder to Accelerate than Others?

B. Make Sense

Use the discussion to help clarify the goals of this workshop. When appropriate, briefly discuss the history of how the views of Aristotle were changed to today's views. This is an excellent time to discuss the use of models in science.

Ideas that participants should recognize include the following:

- **Mass (inertia) is the resistance to acceleration.**
- **Mass is not a force.**

Discuss any remaining questions.

VII-B. Make Sense

1. Much of what was known about physics a long time ago comes to us from the writings of Aristotle who lived in the fourth century B.C. In the "Aristotelian Physics" view if the world, there were four elements on what we would call the planet earth -- earth, water, air and fire. Objects in the heavens were thought to be made of a fifth element, the ether. The natural positions for these elements were earth in the center, water the next level up, then air, fire and ether respectively. There were two types of motion, natural motion and violent motion. Natural motion did not require a force and violent motion did require a force. The following two statements were part of his views:

I. Any object in motion on earth required a force to keep it going. (The only exceptions were objects that were returning to their natural positions, such as a rock that is made of earth falling out of air to its lower natural position.)

II. In the heavens it was a natural motion for objects to go in a perfect circle. Therefore, circular motion did not require a force.

Work in groups to find ways to refute these two statements. Be sure to give evidence for your arguments and be prepared to share your groups views with the whole group.

2. Get out your group's list of important ideas about moving objects, and add any new ideas you have. Also check if there are any previous ideas that need to be modified or abandoned. Be prepared to share your group's ideas in a whole group discussion.

3. Get out your group's list of questions about moving objects. Have any of your groups questions been answered during these last activities? What new questions, if any, have arisen? Add these to your list.

VII. INQUIRE Are Some Things Harder to Accelerate than Others?

C. Apply:

Use the whole-group discussion to clarify any remaining misconceptions.

VII-C. Apply

1. Based on your knowledge of mass, predict what the differences would be if you were to re-do the figure eight activity, but this time used a soccer ball. Describe the differences for each section of the trip (including stopping at the end) and be prepared to share your views with the whole group.

VIII. REFLECT What Have We Learned about Moving Objects?

GOAL:

For participants to reflect on what they have learned, and how they have learned, during the workshop.

APPENDIX Resources and References

Children's Books about Motion

<u>Taxi! Taxi!</u> by Cari Best. <u>Motion</u> **(PreK-2)** Orchard Books.
ISBN 0531070840

<u>The Balancing Girl</u> by Berniece Rabe. <u>Balance</u> **(PreK-2)** Penguin PutnamYoung Read.
ISBN 0525443649

<u>Experiment with Movement</u> by Bryan Murphy. **(Gr. 2-5)** Lerner Pub.
ISBN 0822524511

<u>Gilberto and the Wind</u> by Marie Hall. <u>Wind Movement</u> **(K-3)** Viking Press
ISBN 0140502769

<u>What Makes Things Move</u> by Althea. <u>Movement of Living and Non-living Things</u> **(K-3)**
ISBN 0816721254

<u>Budgie the Little Helicopter</u> by The Duchess of York. <u>Mechanical Movement</u> **(K-3)**
ISBN 068980816X

<u>Hot-Air Henry</u> by Mary Calhoun. <u>Motion and Gravity</u> **(K-4)** William Morrow & Co.
ISBN 0688040683

<u>The Wheels on the Bus</u> by Maryann Kovalski. <u>Movement</u> **(PreK-1)** Little Brown
ISBN 0316502596

<u>Mirette on the High Wire</u> by Emily Arnold McCully. <u>Balance</u> **(K-4)** Putnam Pub.
ISBN 0698114434

<u>All Falling Down</u> by Gene Zion and Margaret Bloy Graham. <u>Gravity</u> **(PreK-2)** Harper Col.
ISBN 006026831X

<u>Gorky Rises</u> by William Steig. <u>Gravity</u> **(K-3)** Sunburst
ISBN 0374427844

NOTE: Most of the above can be ordered through your school library or over the internet at sites such as Amazon.com or Barnes&Noble.