FORCE AND MOTION
(SCIENCE KEY CONCEPTS SERIES: PHYSICS)

FOR USE IN: Physics, General Science **LEVEL:** Grades Optimum 9-12, Optional 7-8
EDUCATIONAL ADVISOR: Dr. O. Roger Anderson, Columbia University, Professor Natural Sciences, Teachers College; and Senior Research Scientist, Lamont-Doherty Earth Observatory

EDUCATIONAL OBJECTIVES:

To help the student understand these three key concepts about force and motion:
- 1. Speed
- 2. Acceleration
- 3. Gravity and the factors that affect falling

BEFORE SHOWING THE VIDEO:

Distance, speed, acceleration, gravity and force are among the most common scientific concepts that students encounter in everyday life. Students often have difficulty differentiating between these concepts and generally they are not well understood. This should not be unsurprising, for thousands of years scientific explanations of motion (kinematics) and its causes (dynamics) were erroneous.

Aristotle and later Buridan held the view that a constant force produces a constant velocity (as opposed to a constantly changing velocity or acceleration). The reason for this is simple. Present scientific ideas about motion and forces (as per Newton and Einstein) are counterintuitive and appear to contradict common sense.

For example heavier objects in many instances do appear to fall faster than lighter objects; and falling objects do not continue to accelerate, but reach a maximum or terminal velocity. These seeming contradictions of scientific theory with the real world are due to the presence of the Earth (and thus gravity) and the air (and thus friction). Despite physics problems containing the rider to "ignore air resistance", it is almost impossible to remove the effects of gravity and friction.

Given this inherent problem it is important that students be provided with opportunity to describe the motion of everyday objects in terms of distances traveled, velocities and accelerations. Suitable example the students might attempt include
a) a car pulling away from rest at a traffic light
b) a car moving at 55mph on the highway
c) the motion of a football as it is kicked off
d) the motion of a ball bouncing twice
e) the motion of a baseball pitched and then hit for a home run.

Further, graphs are a common and useful scientific way of representing motion. Have students predict and explain what the distance-time, velocity-time and acceleration-time graphs for the above motions will look like.

Gravity and falling are also ideas that students find counterintuitive. Many hold the idea that heavier objects fall faster than lighter objects.
A good way to elicit student ideas about this involves a simple demonstration with a book and piece of paper of approximately the same size. Hold the book in one hand and the paper in the other at about shoulder height. Have the students predict what will happen when they are dropped at the same time. Virtually all students will predict correctly that the book will hit the ground first. Ask the students to explain their prediction and most will say because the book is heavier as opposed to invoking air resistance effects.

Repeat the experiment, except this time put the paper directly on top of the book. Again ask the students for their predictions. Most will say the book will fall straight to the ground, while the paper will float down. Drop the book and paper and note that they fall at the same rate. Show the video without further explanation.

CONTENT OF THE VIDEO:

The video explains three key concepts about force and motion, each running 5 minutes and separately titled: Concept #1 Speed, Concept # 2 Acceleration, and Concept #3 Gravity.
To select and play only Concept #2 Acceleration or #3 Gravity, push play and fast forward until you see its title.

Concept #1 SPEED

Speed is defined and measured using a glider on an almost friction-free linear air track. The track has gates every 0.5m. Light beams, connected to timers, are shone across these gates. When the passing glider breaks the light beam across a gate, the timer stops. The average speed (distance/time) of the glider, between each gate, can then be calculated and plotted. When speeds are constant, the result will be a straight-line graph.

A bicycle computer records its average speed at regular distances as the bike increases speed. These speeds are plotted and produce a steeper graph. (Question) What will the graph of a slower moving vehicle look like? (Answer) It will be less steep.

Concept #2 ACCELERATION

V(speed) = D (distance travelled) divided by T (time taken)

Very few things travel at constant speed. When speed increases we call it acceleration. This is demonstrated using time-lapse photography of a golf club swing.

The glider, on the linear air track, is attached to a tape weighted at the end, which makes it accelerate. The time it takes to travel each 0.5m is recorded. When distance traveled is plotted against time, the graph is a curve. When the pulling mass is increased, the graph curve is steeper.
A further mass is added and the following readings were taken, which students can use to plot the acceleration graphs.

	Distance travelled in metres	0.5	1.0	1.5
Test 1	Time taken in seconds	1.8	2.6	3.3
Test 2	Time taken in seconds	1.4	2.0	2.4
Test 3	Time taken in seconds	1.1	1.6	1.9

Concept #3 GRAVITY

Bungee jumping, rain falling, and high diving are shown as examples of the effects of gravity as a pulling force. We also see the interior of a space capsule to show the effects of zero gravity. Do all divers fall at the same rate? Does their mass make a difference?

Two balls, of the same size but differing mass, are dropped from the same height, to see if mass affects the rate of fall. It does not. Balls of similar mass, but very different sizes are dropped from the same height. Will they fall at the same or different rates? The larger ball is slower because of the frictional resistance of the air molecules against it.

Watching a film of a melon dropped from a tall building, you can see that its speed increases as it falls. It accelerates until it reaches a maximum acceleration rate of 10m/sec/sec.

AFTER SHOWING THE VIDEO:

A good first question after showing the video is why use an air track to study motion?

The air does 2 things, a) it counteracts the effect of gravity by providing an upward force, and b) by preventing the solid glider and track from contacting it reduces friction to a very small value. Essentially the air track makes conditions that are close to forceless so that gravity and friction can be ignored.

Students should be able to distinguish between speed and velocity. Speed is a scalar quantity (i.e. no direction needs to be specified) and has only positive values, while velocity is a vector and the direction must be specified. Velocity can have positive and negative values, representing backwards and forwards motion.

Students should also be able to draw distance-time graphs, velocity-time graphs and acceleration-time graphs for the following types of motion; a) slow, b) faster, c) stopped, d) constant forward velocity, e) constant backward velocity, f) speeding up, g) slowing down. Student should be able to describe how these graphs are interrelated.

A challenge would be to have students describe graphically a variety of everyday motions e.g. a plane taking off. In terms of acceleration, students often mix up high velocity with acceleration. For example, many consider that a car can only pass another car on the highway if it is accelerating, even though it is probably moving at a higher constant velocity.

Students should also be aware that the units of acceleration are meters per second squared or (m/s2).These units derive from changes of velocity in a given time (i.e. meters per second changes every second). An intuitive way to overcome difficulties that students have with this unit is to mix the units (e,g, mph per second). This is exactly what car manufacturers do in their advertisements - a car's "power" is shown by its ability to go from zero to 60 mph in the least number of seconds (i.e. mph per second). The car manufacturers are simply describing the car's acceleration.

Re gravity and falling: Students should be made aware of some of the semantic issues regarding the use of the word "gravity". Gravity is not really a force, but is a mutual attraction of objects (though Einstein defines it differently). The actual force related to gravity is known as
weight.

Students should be able to distinguish mass (a universal constant) from weight (a variable quantity). The change in motion of an object that is falling is known as the acceleration due to gravity. The issue of the independence of falling and the mass of an object can be illustrated with a number of every day examples, e.g. students could be asked to explain what happens to a parachutist during the various sections (free-falling, reaching terminal velocity, opening the parachute, and reaching a second lower terminal velocity) of her/his fall.
Students should be able to describe the motion of the parachutist in terms of velocity, acceleration and the various forces acting. Finally, the student should attempt to explain the results of the book and paper demonstration that was suggested be shown them in the “BEFORE SHOWING THE VIDEO” section.

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