MiSP FORCE AND GRAVITY
Teacher Guide, L1 – L3

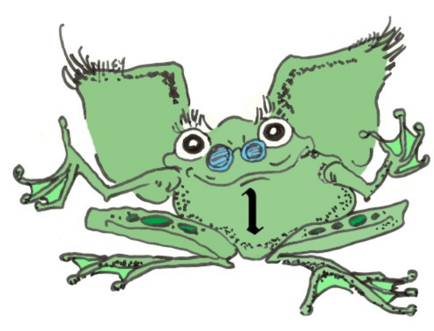
Introduction

This unit uses BASE jumping and skydiving to illustrate Newton's three laws of motion and to explore the concept of gravity. The activities are either taken directly from or modified from ideas in *Gravity Rules!* (AIMS Education Foundation, 1998). Gravity is used as an example of a force. The students must have a good understanding of the concepts of velocity and average velocity before beginning this unit. The MiSP Motion unit covers these topics. A preliminary understanding of force is also important. Day 1 of this unit reviews force concepts and introduces the concept of acceleration, using acceleration due to gravity as an example. Data for the velocity of a falling object at every second for the first ten seconds are presented. The data given ignore the effect of air resistance. Students will graph the data to determine the constant acceleration, which is the acceleration due to gravity.

On day 2 the effects of air resistance are taken into account. The students view a video (AIMS Education Foundation, 1998) of a BASE jump from the New River Gorge Bridge in West Virginia. They then use free fall data, published in *Skydiving* magazine, which show the total distance an average BASE jumper will have dropped at every second of a free fall. The students then calculate the acceleration during each second. They see that acceleration decreases until it reaches zero; this is defined as terminal velocity.

Skydiving is used to illustrate Newton's laws of motion on day 3. The force acting on the skydiver is gravity. The weight of the skydiver is a measure of this force. Because the force is applied constantly, a skydiver accelerates as he/she falls. As the downward velocity of the skydiver increases, a retarding force caused by the friction of falling through the air pushes upward on the skydiver. The force is called *air resistance*. After about 12 seconds of free fall, the forces acting on the skydiver are balanced and the skydiver continues to fall at a constant velocity called *terminal velocity*. The skydiver in the video reaches a terminal velocity of about 185 feet per second (about 126 miles per hour), a velocity that is much too fast for a safe landing! To slow down, the skydiver opens a parachute, which increases the air resistance and decreases the downward velocity.

Students will watch a video and collect data. The altimeter used in the video is not stable enough to allow for a calculation of free fall acceleration, but the students can graph total average velocity and then break the data into two segments: free fall and fall under canopy (after a parachute is opened).



Standards

ILST Core Curriculum — Major Understandings:
Standard 4 Physical Setting 5.1b, 5.1c, 5.1d, 5.2a

Learning Objectives: After completing this unit, students will demonstrate understanding of the following concepts:

- **Motion** is the result of the combined effect of all **forces** acting on the object.
- A moving object that is not subjected to a force will continue to move at a constant speed in a straight line. An object at rest will remain at rest.
- Force is directly related to an object's **mass** and **acceleration.** The greater the **force,** the greater the change in motion.
- For every action there is an equal and opposite **reaction.**

Day 1 — Review of Newton's Laws and Introduction to Gravity

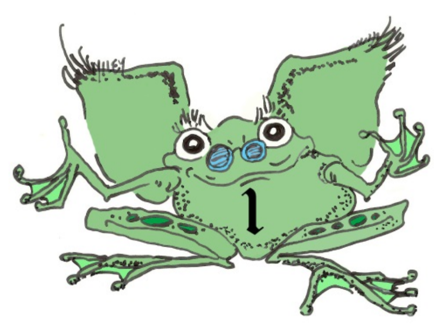
Use toy cars to begin your instruction on forces. Set a small toy car (e.g., a Matchbox car) and a somewhat larger toy car on top of a desk.

- Ask the students why the cars do not move.
- Flick the small car with your finger. What made the car move?
- Flick the larger car with your finger. Why didn't it move?
- Flick the small car again. Why did the car stop?
- Place the car at the top of an inclined plane and let it roll down. What made the car move? What made it stop?
- What would happen if there were no friction?

A force had to act on the car in order to move it. The greater the mass of the car, the greater the force needed to move it. Friction will slow the car down. In the absence of continued force, frictional forces stop the car. If you continue to push the car with just enough force to overcome the friction, it will move at a constant speed. The car will accelerate if the "pushing" force is greater than the frictional force.

The activity with the toy cars is just an illustration of Newton's first law: An object's **motion** is the result of the combined effect of all **forces** acting on the object. A moving object that is not subjected to a force will continue to move at a constant speed in a straight line. An object at rest will remain at rest.

There are many different types of force:



- In <u>contact force</u> there is a direct connection between the source of the force and the object on which the force is exerted. An example is the pushing or pulling of an object.
- <u>Electric charge</u> and <u>magnetic force</u> are repulsive or attractive forces between two magnets or electrical charges.
- <u>Gravity</u> is an attractive force between any two objects that depends on the mass of each object and the distance separating the centers of gravity. In this unit gravity will serve as an example of a force. In everyday life, gravity is the force that causes things to fall when we drop them.

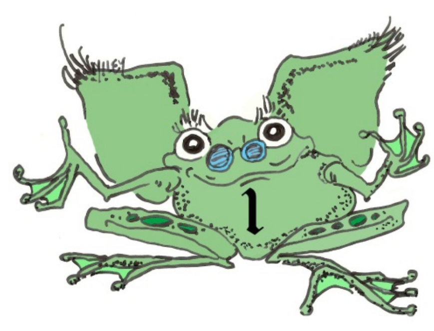
Measuring actual forces in the classroom is difficult because frictional forces are hard (impossible, in fact) to eliminate. We can use gravity as an example because we know the acceleration due to gravity.

Newton's second law of motion states that force = mass * acceleration. Force needed to move an object = mass of the object * acceleration (the amount by which speed is increasing or decreasing each second).

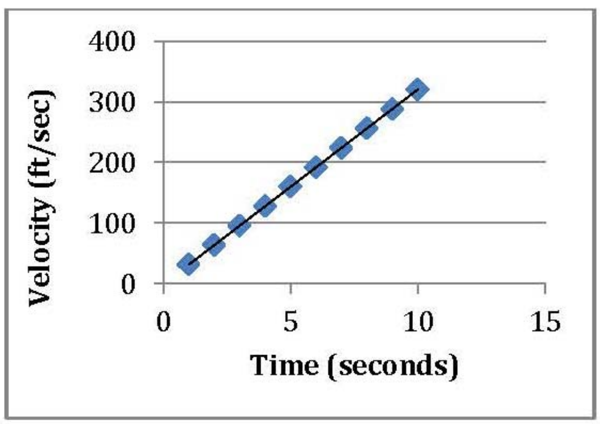
A force acting on an object will cause it to move if the force is great enough to overcome the inertia of the object. The mass of the object is a measure of its inertia. If the force is removed, the object will continue to move at the same speed until some other force limits its motion. If force continues to be applied, the speed of the object will continue to increase until some limiting force limits its speed. In the skydiving example on day 3, the velocity at which the skydiver falls will continue to increase because of the force of gravity. This increasing velocity is known as acceleration. Acceleration = the change in velocity per unit of time ($a = \Delta v/\Delta t$).

Calculating the Acceleration due to Gravity:

Suppose you dropped a pumpkin from the top of the world's tallest freestanding structure: the 828 m tall (2,717 ft tall) Burj Khalifa in Dubai, United Arab Emirates. The velocity at which the pumpkin was falling toward Earth at the end of each second (neglecting air resistance) is given below. The data are presented in units of m/sec and in ft/sec. (Note: Use of the metric system is preferable. However, the subsequent activities, adapted from *Gravity Rules!*, use the American system of measurement.)



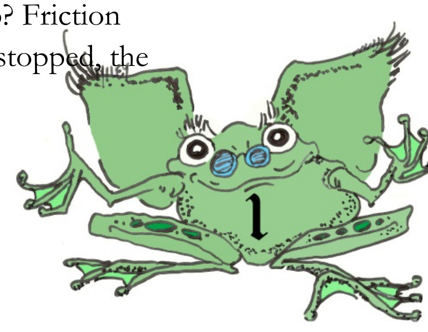
Time (seconds)	Velocity (m/sec) No resistance	Velocity (ft/sec) No resistance
1	9.8	32
2	19.6	64
3	29.4	96
4	39.2	128
5	48	160
6	57.8	192
7	67.6	224
8	77.4	256
9	87.2	288
10	97	320



Day 2 — Combining Gravity and Resistance, Part 1

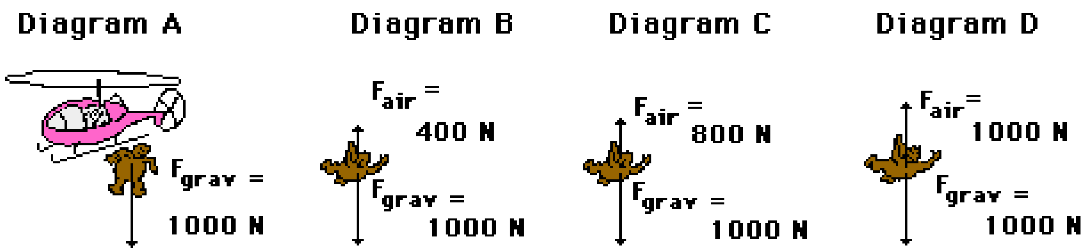
Gravity is not the only force acting on a moving object. The air resists the movement of an object through it. Friction is generated when an object moves in air, and this frictional force is called *air resistance*. It acts in a direction opposite to gravity. The velocity at which an object moves is the combined result of the force exerted on it and the resistance forces that oppose the movement.

1. Repeat the demonstration with the Matchbox cars. Why did the cars stop? Friction (mostly between the wheels of the car and the surface) slowed, and then stopped, the car.

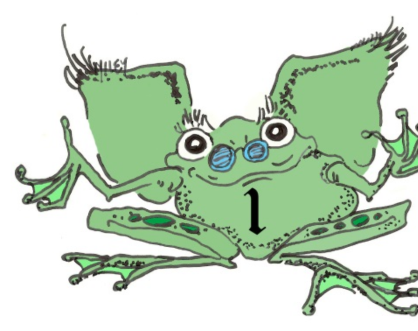


2. A pumpkin dropped from Burj Khalifa or a person jumping from an airplane or tall manmade or natural structure (BASE jumping) would be slowed down somewhat by air resistance. As a skydiver or a BASE jumper in free fall (i.e., falling without an open parachute) accelerates due to the acceleration of gravity, the force of air resistance also increases. The velocity at which an object moves is the combined result of the force exerted on it and the resistance forces that oppose the movement. Eventually a point is reached where the force due to gravity is equal to the air resistance force and the object no longer accelerates. At this point the moving object has reached terminal velocity. This happens after approximately 12 seconds of free fall.

The graphic below (from http://www.physicsclassroom.com/mmedia/newtlaws/sd.cfm) illustrates terminal velocity:



3. Student Activity
   View the video of the BASE jumpers on the *Gravity Rules!* DVD. The narrator notes that in order for jumpers to know how long they can wait before opening their parachute during a BASE jump, they must know how high above the ground they are before they jump and how fast they are moving during the jump. The data below, showing distance fallen after each second of free fall, were originally published in the June 1991 issue of *Skydiving* magazine. In this activity the students calculate velocity (unit rate of change) and acceleration for each second of free fall from Burj Khalifa, using the free fall table below. In the BASE jump free fall table, they will see that the velocity stays the same after 12 seconds of free fall. The students should also realize that a skydiver or BASE jumper will have to slow down before landing if he/she expects to survive the jump. Terminal velocity is 176 feet/second (120 miles/hour).

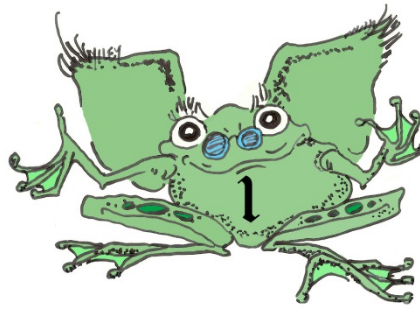


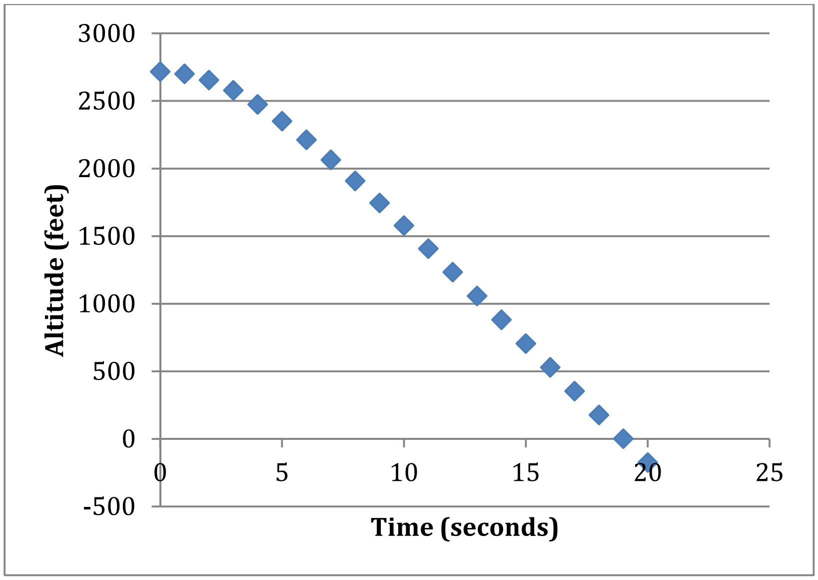
BASE Jump Free Fall Table				
Time (sec)	Total distance fallen (ft)	Altitude	Velocity Δd/sec	Acceleration Δvelocity/Δt
0	0	2717		
1	16	2701	16	
2	62	2655	46	30
3	138	2579	76	30
4	242	2475	104	28
5	366	2351	124	20
6	504	2213	138	14
7	652	2065	148	10
8	808	1909	156	8
9	971	1746	163	7
10	1138	1579	167	4
11	1309	1408	171	4
12	1483	1234	174	3
13	1659	1058	176	2
14	1835	882	176	0
15	2011	706	176	0
16	2187	530	176	0
17	2363	354	176	0
18	2539	178	176	0
19	2715	2	176	0
20	2891	-174	176	0

Free Fall Table	
Time (sec)	Distance Fallen (ft)
1	16
2	62
3	138
4	242
5	366
6	504
7	652
8	808
9	971
10	1138
11	1309
12	1484
13	1659
14	1835
15	2011
16	2187
17	2363
18	2539
19	2715
20	2891

The students calculate the altitude based on a starting altitude of 2,717 feet (height of Burj Khalifa) and the velocity in each consecutive one-second period. They then graph the altitude at each second. See graph on the following page.

In the analysis section, they measure the unit rate of change between two sets of points and recall that a difference in location divided by a difference in time is velocity. They note that the velocity changes over time and that it decreases each second up to the interval between 13 and 14 seconds. They then calculate the acceleration between each set of consecutive seconds and note that acceleration becomes 0 between 13 and 14 seconds. This velocity is defined as *terminal velocity* for the students. Questions in the analysis section probe the reasons for the changing velocity.

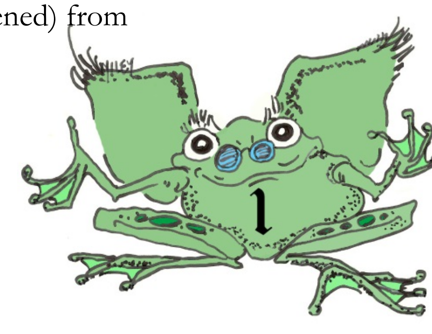




Supplemental information:
If there were no atmosphere, all objects would fall at the same rate. This happens, for example, on the moon. David Scott, commander of the Apollo 15 mission, demonstrated this while standing on the moon's surface. He dropped a hammer and a falcon's feather (the Apollo 15 lunar module was called Falcon*) at the same time from the same height. In the airless vacuum of space, the feather and the hammer both fell straight down, reaching the lunar surface at the same instant.*
See:
Apollo 15 *Hammer* and *Feather* Drop
www.youtube.com/watch%3Fv%3D-4_rceVPVSY&rct=j&sa=X&ei=5V8qTYn-NsPflgeG1OSiAQ&ved=0CEwQuAIwAw&q=David+Scott+feather+and+hammer&usg=AFQjCNGdvCvNwgn4Pp9esWkJLUeojWrNDg

Days 3 and 4 — Combining Gravity and Resistance, Part II

Instruction for this day uses "Fall Timers," an activity in *Gravity Rules!* (p. 49). In this activity, students view a video of a typical skydive recorded by a skydiver who had carried a video camera along with a skydiving altimeter. The students collect and record time and altitude data directly from the video. Then they graph and analyze the data and compute the average velocities. The altimeter records several aberrant values at the beginning of the jump due to the abrupt change from the still air in the cabin of the airplane to the ~100 mph airstream. The skydiver accelerates to approximately 140 mph in about 12 seconds and then maintains that velocity for ~50 seconds. The skydiver then decelerates (parachute is opened) from about 180 feet/second to 10 feet per second in less than 2 seconds.



Students first practice reading the altimeter. A worksheet to guide this practice is provided with the workbook (FallTimers.pdf). Students then view the video in its entirety to become familiar with the sequence. They view the video a second time, and record on Worksheet #3 the time and altitude at which the skydiver leaves the plane and the time and altitude when she lands. They graph these two data points and calculate average velocity. The questions that accompany the graphing activity ask the students to recognize that the graph is inaccurate because it does not depict the changes in velocity.

Next, the students view the video a third time but this time they also record the time and altitude at 14 seconds into free fall and at the point when the skydiver opens her parachute. Students graph the three segments of the fall. At Level 1 they calculate the average velocity of each segment of the fall and answer questions probing the relationship of the changing velocities to the forces acting on the skydiver. At Level 2 the students calculate the unit rate of change during each segment of the fall and are prompted to recognize this as the average velocity of each segment. Students then answer questions probing the relationship of the changing velocities to the forces acting on the skydiver. At Level 3 the students write equations for lines representing each segment of the fall. They must extrapolate back to $x = 0$ to determine the y-intercept. Students are prompted to recognize that the extrapolation causes the calculated altitude at the beginning of the skydive to change.