LESSON PLAN – Gravity Check

Academic Subject: Physics, physical science

Academic Topics: g forces, centripetal acceleration

Background: Dave Mirra knows a thing or two about riding the Vert. This BMX rider has won more X games gold medals than anyone else in history. He knows that the higher he starts on an entrance ramp, the higher he can go on the other side. However, he also knows that there must be a limit to how high an entrance ramp can be. If the entrance ramp is too high a rider will go too fast on the bottom curve. It turns out there is such a thing as too fast around a circle – it translates to too many g's.

Discussion:
Every object with mass is pulled on by the Earth with a force that is equal to mass x acceleration due to gravity. The name given to this force is weight.

$$\boxed{w = mg}$$

The acceleration due to gravity is used so often it has a symbol – lowercase g. The value of g is 9.8 m/s^2 towards the earth. If an object is released from rest and gravity is the only force acting on it, the object will gain 9.8 m/s of speed for every second that it falls.

The force of gravity acts at a distance – meaning it is always present between two masses even if they are not touching. People tend to notice forces that result from direct contact. A man standing on the ground can feel the ground pushing up on his feet but doesn't feel the pull of the earth on him towards its center. The man is in vertical equilibrium so the ground pushes up on the man with a force equal to his weight. He can gauge his weight based on how hard the ground pushes him up. A scale measures the force of the ground pushing up on the person which happens to be equivalent to weight.

If the man were to accelerate up in an elevator, the floor of the elevator would have to push with a force greater than his weight. When this happens, the man feels like he is heavier because he is used to equating the force from the floor with his weight. The scale reading would also be larger than the weight due to earth's gravity. His real weight doesn't change of course, but his apparent weight does. His apparent weight would decrease if he accelerated down in an elevator. In this case the floor pushes with a force that is less than the actual weight.

A g-force is the amount of force someone experiences when he/she accelerates at the same rate as gravity – 9.8 m/s^2. A person accelerating at 9.8 m/s^2 feels one g-force. Someone accelerating at 19.6 m/s^2 experiences two g-forces and someone accelerating at 49 m/s^2 is pulling five g's.

$$\boxed{\#g's = \frac{acceleration}{9.8m/s^2}}$$

Too many g's can be dangerous for the human body. A person experiencing more than 8g's for a sustained period will become unconscious. For this reason, roller coaster engineers are limited to how many g-forces ride occupants can experience when on a ride. (Typical roller coasters have a maximum of 3g's, although there are exceptions that are a little higher.) The same is true of riding the Vert – the biker cannot experience a dangerous number of g-forces. In order to determine how many g's a rider experiences at the bottom curve of the Vert, we need an equation that allows us to solve for acceleration at that location.

$$\boxed{a = \frac{v^2}{r}}$$

This equation yields the acceleration of an object moving with a speed v around a circle with a radius of curvature r. Although the bottom of the Vert is just a curve and not a full circle, the radius can be determined by considering the circle the curve would make if extended. The radius of curvature at the bottom of the Vert is 3.3 m. The speed of a rider around this curve can be found using conservation of energy. The following equation can be used to determine how fast a rider travels at the bottom of the Vert when starting from rest:

$$KE_{top} + PE_{top} = KE_{bottom} + PE_{bottom}$$

$$0 + \cancel{m}gh = \frac{1}{2}\cancel{m}v^2 + 0$$

$$\boxed{v = \sqrt{2gh}}$$

where g is acceleration due to gravity (9.8 m/s^2) and h is the initial height in meters.

When riders start from a height of 9 meters they riders go around this curve at 13 m/s Plugging into the equation for acceleration, a rider accelerates at a rate of 54.4 m/s^2. Dividing this by the acceleration due to gravity tells us that the rider experiences 5.5 g's! No wonder entrance ramps are not built any higher.

Extending the Lesson:

If there is access to an elevator, have students stand on a scale while the elevator makes a round trip. The scale records how much it is pushing up on the student. As the elevator begins to rise the scale should read higher than usual, once the elevator moves up at constant speed it should read the normal weight, and when the elevator starts to slow down it should read less than usual. On the way down it should read lower, normal, and then higher. Discuss why the scale readings fluctuate the way they do. Students can also report on elevator passenger reactions to their physics experiment.

ACTIVITY SHEET

1. A poorly designed Vert causes riders to experience too many g's at the bottom of the ramp. What are two modifications that can be made to the Vert to make it safer?

2. How many g-forces does a driver experience when driving around a circular track at 15 m/s if the radius of the track is 12 m?

3. A rider starts from rest and descends the Vert from an initial height of 7 m. How many g-forces does the rider experience at the bottom of the ramp if the radius of curvature is 3.6 m?

4. Race car driver David Purley survived a record number of g-forces in 1977 when he crashed into a wall at 48 m/s (almost 100 miles per hour!). His car came to a complete stop in a distance of 66 cm. How many g's did he experience?

ANSWERS

1. a) Height of ramp can be decreased to lower speed of riders at the bottom.
   b) Ramp can curve more gradually to increase the radius of curvature.

2. $$a = \frac{v^2}{r} = \frac{15^2}{12} = 18.8 m/s^2$$
   $$\# g's = \frac{18.8}{9.8} = \boxed{1.9 g's}$$

3. $$v = \sqrt{2gh}$$
   $$v = \sqrt{2(9.8 m/s^2(7m)}$$
   $$v = 11.7 m/s$$
   $$a = \frac{v^2}{r} = \frac{(11.7 m/s)^2}{3.6m}$$
   $$a = 38.1 m/s^2$$
   $$\# g's = \frac{38.1 m/s^2}{9.8 m/s^2} = \boxed{3.9 g's}$$

4. $$v^2 = v_0^2 + 2ax$$
   $$0 = (48\frac{m}{s})^2 + 2a(0.66m)$$
   $$a = 1750 m/s^2$$
   $$\# g's = \frac{1750 m/s^2}{9.8 m/s^2} = \boxed{178 g's!}$$