Physics Workshop
Centripetal Motion
Suggested Checkpoint Questions with Answers

- Checkpoint following 1(c):

1. What is the direction of the net force in each of your free-body diagrams? How do you know?
2. Which force or forces are supplying the net force in each case? Can a net force ever consist of a combination of forces? Try to think of an example where this is the case.

- Checkpoint following 2:

1. Which force or forces are acting as the "centripetal force" in this problem? Is the centripetal force always a single force, or can it be a combination of forces?
2. Suppose the car was going faster than 30 m/s when it encountered the hill. What does your expression for the normal force indicate in that case? Can a normal force be negative in magnitude?
3. How much force, as a function of angle, must friction supply to the car if it is to maintain constant speed on the hill?

- Checkpoint following 3:

1. Can you summarize the circumstances under which the normal force on an object is equal to the object's weight?
2. How can static friction (as opposed to kinetic friction) apply to the case of a moving car?
3. Why are the coefficients of friction given as approximate, rather than exact values?

- Checkpoint following 4:

1. What force or forces are acting as the centripetal force in each case?
2. About how many revolutions per second is the ball making, given the numerical values from part (c)?

- Checkpoint following 5:

1. Is the boy's motion a case of motion with constant acceleration? Can you apply the standard kinematics equations to determine how far he swings before releasing the rope?

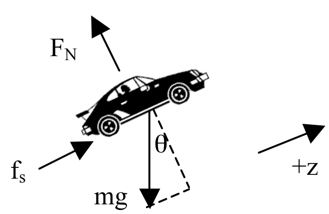
Answers to checkpoint questions:

- Checkpoint following 1:

1. The direction of the net force in each case is inward, towards the center of the circular motion, because these are all cases of circular motion with constant speed. If you draw the velocity vectors at any two times and subtract them, you will see that the resulting average acceleration (change in velocity) always points towards the center of the circle.
2. In the first two cases, static friction is supplying the net force. In the last case, the force of gravity between the Earth and the Sun supplies the net force. There are many cases where more than one force combines to supply the net force. A simple example is a skydiver at terminal velocity, where the forces of gravity and air resistance combine to yield zero net force.

- Checkpoint following 2:

1. Here it's actually the car's weight *minus* the normal force that serves as the centripetal force. The term centripetal force is simply used to mean whatever force or combination of forces point towards the center of circular motion, since the forces in that direction are causing the object's inward (centripetal) acceleration.
2. A speed greater than 30 m/s would seem to indicate that the normal force would have to be negative. This means either that the car has left the road and is no longer moving in circular motion (so that the equation for the normal force is no longer valid) or that the normal force is in fact pointing in the direction opposite to what's shown on the FBD. This would mean that there's a force actually holding the car to the road, which doesn't typically occur on regular roads but which happens with rollercoasters, for example.
3. Drawing a FBD for some arbitrary place in the car's motion and applying Newton's 2nd Law in the direction tangent to the motion (I'll call it the z-direction):



$$\Sigma F_z = ma_z :$$
$$f_s - mg\sin\theta = 0$$
$$\Rightarrow f_s = mg\sin\theta$$

The force of friction (and therefore the power output of the engine) is larger at first and decreases as the car nears the top of the hill.

- Checkpoint following 3:

1. The normal force on an object is typically equal to the object's weight only when the object is on a horizontal surface, is not accelerating vertically, and has no vertical forces acting on it other than the normal force and the weight.
2. If you look carefully at the point of contact of a rolling object with the ground, you can convince yourself that it's actually at rest with respect to the ground, unless the object skids. Therefore it's static friction that acts.
3. Coefficients of friction are typically determined experimentally and vary with factors such as temperature, humidity and the cleanliness and exact compositions of the surfaces. The numbers quoted in textbooks are therefore useful but inexact approximations.

- Checkpoint following 4:

1. When the ball is at the side of the circle, only the tension points towards the center, so tension is therefore acting as the centripetal force. At the top of the circle, the tension *plus* the weight acts as the centripetal force. At the bottom of the circle, it's the tension *minus* the weight.
2. The circumference of the circle is $2\pi R \approx 6$ m. Since the ball is moving at 6 m/s, it is making about one revolution per second.

- Checkpoint following 5:

1. The boy is moving in a circle and slowing down, so this is not motion with constant acceleration in any direction and the equations of kinematics with constant acceleration cannot be applied. One way to analyze this problem is using calculus, and another is to use energy methods, which you will probably learn in a few weeks or less.