**SIMULATION 13A: A Block Moving Up a Hill**

**PHYSICS REVIEW**

When an object such as a block is placed on an inclined plane, it will slide down with a constant acceleration. It is important here to remember the definition of acceleration: acceleration is a change in velocity, in either magnitude or direction (or both). The magnitude of the acceleration depends on the angle of inclination ($\theta$) which is measured with respect to the $x$ axis. The direction of this acceleration direction is always down the hill, and its magnitude is a fraction of the gravitational acceleration of the block. It can be treated as motion in one dimension with the positive direction defined as up or down the plane. Then the same equations for position, velocity, and acceleration for one-dimensional motion with constant acceleration will be valid. It is important to note that the speed of an object is the velocity without regard to positive or negative values: speed is equal to the magnitude of the velocity, but it is always positive.

Formulas you should be familiar with:

\[
\begin{align*}
    a &= \frac{\text{change in velocity}}{\text{time interval}} \\
    v &= v_0 + at \\
    \text{velocity} &= \text{initial } v + (\text{acc} \times \text{time})
\end{align*}
\]

This is the same as

\[
    a = \frac{v - v_0}{t}
\]

Reference topics: inclined planes, velocity, acceleration

**SIMULATION DETAILS**

In this simulation, a cavewoman is playing mini golf. The idea of this simulation is to explore what happens when a block with an initial velocity travels up a hill. The angle of inclination of the hill is fixed at 30°. This makes the acceleration equal to 4.9 m/s$^2$, directed down the hill. When you run the simulation, a block will be projected up the hill with an initial speed that you can adjust. You will also be able to note: $a = g \sin \theta = (9.8) \sin 30 = 4.9 \text{ m/s}^2$. It is directed down the hill so it is negative.
to adjust the mass of the block. There is no friction between the block and the hill. The simulation will automatically stop when the block has returned to (or near) its original position, land in the hole, or goes out of the field of view. Output meters of position, velocity, and acceleration will allow you to study their relationships. The positive direction is up the hill.

If the cavewoman hits the block with an initial speed of 9 m/s, it will go up the hill and then come down again. Predict what the velocity and acceleration graphs will look like for this case.

Note: Acceleration is the slope of the velocity graph. It is negative and constant.

What will the acceleration of the block be when it reaches its maximum distance up the hill? 

-4.9 m/s² Note: It is always -4.9 m/s². It comes from the gravitational force on the block. A common misconception is that it is zero at the top. Ask students why gravity would go away at that instant.

What will its velocity be at that point?

Its velocity is zero. When it turns around, it goes from having a positive velocity to a negative velocity so it must have zero for an instant.

Set the initial speed to 9 m/s, the mass to 3 kg, and click Run. Observe the motion of the block.
From the simulation data, record or calculate the following:

1) The time it takes for the block to reach the top of the hill is \(1.84\text{ s}\). They will need to go back to where \(v\) is closest to zero.
2) The distance that the block traveled up the hill is \(6.4\text{ m}\).
3) The acceleration of the block at the top of the hill is \(-4.9\text{ m/s}^2\).
4) The velocity of the block at the top of the hill is 0. Small positive or negative numbers are okay, but they should understand it is zero.

How do these last two values compare with your predictions?

3) Most students will not have their prediction for acceleration agree. Most students should have correct prediction for velocity.

From the simulation data, record or calculate the following (for the initial \(v = 9\text{ m/s}\)):

5) The time taken for the block to complete its motion is \(3.68\text{ s}\).
6) The velocity of the block when it returns to the bottom of the hill is \(-9\text{ m/s}\).
7) The acceleration of the block at the bottom of the hill is \(-4.9\text{ m/s}^2\).

Predict which of the above quantities will be affected (and how) by decreasing the initial speed of the block.

1) The time will be smaller.
2) The distance up the hill will be smaller.
3) The acceleration should not change.

Set the initial speed to 7 m/s, leave the mass at 3 kg, and click Run. Observe the motion of the block.
Use the simulation data to fill in the table below.

<table>
<thead>
<tr>
<th>Velocity on an Inclined Plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>velocity</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>9 m/s</td>
</tr>
<tr>
<td>7 m/s</td>
</tr>
</tbody>
</table>

Which of the above quantities were affected (and how) by decreasing the initial speed of the block?

1) Time-up: **it decreased**
2) Distance-up: **it decreased**
3) Accel-top: **it remained the same**

Now, we will look at changing the mass of the block.

Predict which of the above quantities will be affected (and how) if you increase the initial mass of the block.

1) **the same**
2) **the same**
3) **the same**

**Note:** Students may predict that the time up and the distance travelled up will be less. This stems from the misconception that larger masses are somehow more impeded and won't go as far.
Set the initial speed back to 9 m/s, set the mass to 5 kg, and click Run. Observe the motion of the block.

Use the simulation data to fill in the table below.

<p>| Mass on an Inclined Plane (v=9 m/s) |
|---|---|---|---|</p>
<table>
<thead>
<tr>
<th>mass</th>
<th>time - up</th>
<th>distance-up</th>
<th>accel-top</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 kg</td>
<td>1.84 s</td>
<td>6.4 m</td>
<td>-4.9 m/s²</td>
</tr>
<tr>
<td>5 kg</td>
<td>1.84 s</td>
<td>6.4 m</td>
<td>-4.9 m/s²</td>
</tr>
</tbody>
</table>

Which of the above quantities were affected (and how) by increasing the initial mass of the block?

1) Time-up: *stayed the same*
2) Distance-up: *stayed the same*
3) Accel-top: *stayed the same*

**Note:** You could point out here that there is no mass variable in the equation

\[ v = v_0 + at \]

Predict how the following will or will not change by decreasing the mass to 1 kg.

In what follows, circle the correct word.

- The time to get to the top will (be larger, be smaller, *stay the same*).
Set the initial speed to 9 m/s, the mass to 1 kg and click Run. Observe the motion of the block.

Were your predictions correct? Why or why not? More discussion if needed on no mass variable therefore no dependence on mass.

Adjust the initial velocity to find a value that makes the block land in the square hole. What is this value? 9.5 m/s should work. The velocity graph is no longer smooth due to collisions with the hole.

What happens to the block if the initial velocity is above this value?

It will go past the hole and over the hill. The velocity graph goes abruptly from positive to negative. This is okay, don't focus on it, but if a student asks, that is how interactive physics works.

The acceleration graph is quite varied. This is because the block hits a rocky surface several times. Don't dwell on this. In the ideal situation, once free of the hill the block will be in free-fall with an acceleration of \(-9.8 \text{ m/s}^2\).
Self-test Questions for Simulation 13A

The following statements refer to a block being propelled up a hill which is inclined upward at 30°. True or false?

1. The distance a block will travel up the hill depends on the initial speed of the block. True - refer to table comparing initial speeds of 9 m/s and 7 m/s.
2. If the mass of the block is larger, the distance traveled up the plane will be less. False - refer to table comparing 5 kg to 3 kg.
3. The smaller the mass, the less time it takes to travel 1 meter up the hill. False - same as above
4. The speed of the block when it returns to the bottom is the same as its initial speed. True - speed is velocity not including the direction (+ or -). Speed = |velocity|
5. The acceleration of the block depends on the mass of the block. False - there is no mass variable in \[ a = g \sin \theta \]

Simulation 13B is suggested for grades 7-8. If you want your students to investigate the effect of friction, you can do some or all of 13B. Students will likely need more clarification and guidance from you.