

## Preparation for Teaching a Lab

The following pages contain 6 authentic student answers to the Warm-up questions for a 1301 lab problem: Force and Motion. It is the first lab that addresses the physics concept of *force*. This particular set of solutions was from 2004.

During the semester you will collect your students' answers to the lab problem warm-up questions 1-2 days prior to teaching the lab. Collecting the answers in advance will help you prepare to teach the lab.

For this activity, look at the 6 student solutions to warm-up questions. Try not to spend too much time on each one – during the semester your time will be very limited! Use these student solutions to get a general idea for the students' understanding of the lab problem. A copy of the warm-up questions is provided for you to see what students were following.

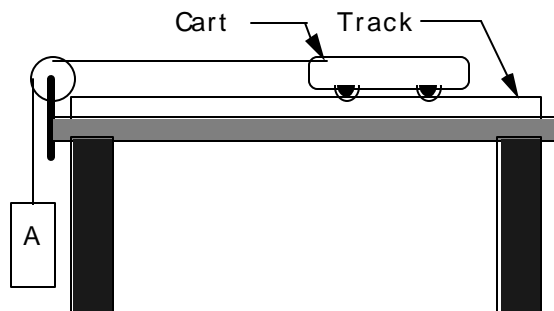
As you look through the students' solutions, take note of which questions the students have most difficulty with. Think about how you can address their common mistakes or issues in lab. What will you ask students to write on the board at the beginning of lab? What questions will you ask students during the opening discussion?

Use the Lab Preparation sheet following the student solutions to make notes about how you would prepare for a lab session, based on the papers of these 6 students.



Warm-up Questions for 1301 Lab 3 Problem #1: Force and Motion  
(2004 edition; formerly called Method Questions)

**Released from rest, a cart is pulled along a level track by a hanging object as shown below:**



You will be able to vary the mass of Object A (the “mass hanger”) and the Cart. They are connected together using a light string. Object A falls through a distance which is significantly shorter than the length of track. You will have a meter stick, a stopwatch, a mass hanger, a mass set, cart masses, a pulley, a pulley clamp, one piece of string and the video analysis equipment. In this experiment we ignore the friction between the cart and the track.

**PREDICTION**

Calculate the cart’s velocity after object A has hit the floor, as a function of the mass of the object A, the mass of the cart, and the distance object A falls.

Make a graph of the cart’s velocity after object A has hit the floor, as a function of the mass of object A for the same cart mass and height through which object A falls.

Make a graph of the cart’s velocity after object A has hit the floor, as a function of the mass of the cart for the same mass of object A and height through which object A falls.

Make a graph of the cart’s velocity after object A has hit the floor, as a function of the distance object A falls for the same cart mass and mass of object A.

**WARM-UP QUESTIONS**

To test your prediction, you must determine how to calculate the *velocity* from the quantities you can measure in this problem. It is useful to have an organized problem-solving strategy such as the one outlined in the following questions. You might also find the Problem Solving techniques in the Competent Problem Solver useful.

1. Make a sketch of the problem situation similar to the one in the Equipment section. Draw vectors that show the direction and relative magnitude of the motion of the objects (velocity and acceleration) at the interesting times in the problem: when the cart starts from rest, just before the object A hits the floor, and just after object A hits the floor. Draw vectors to show all of the forces on object A and the cart.

Assign appropriate symbols to all of the quantities describing the motion and the forces. If two quantities have the same magnitude, use the same symbol but write down your justification for doing so. For example, the cart and object A have the same magnitude of velocity when the cart is pulled by the string. Explain why. Decide on your coordinate system and draw it.

2. The “known” quantities in this problem are the mass of object A, the mass of the cart, and the height above the floor where object A is released. Assign these quantities symbols so that you can use them in algebra. The unknown quantities are the velocity of the cart and of object A just before object A hits the floor. There are other unknowns as well. List them. What is the relationship between what you really want to know (the velocity of the cart after object A hits the floor) and what you can calculate (the velocity of the cart just before object A hits the floor)?
3. Write down what principles of Physics you will use to solve the problem. Because forces determine the motion of the cart, using Newton’s 2<sup>nd</sup> Law to relate the sum of the forces on each object to its motion is a good bet. Since you need to determine forces, Newton’s 3<sup>rd</sup> Law is probably also useful. Will you need any of the principles of kinematics? Write down any assumptions you have made which are necessary to solve the problem and justified by the physical situation.
4. Draw separate free-body diagrams for object A and for the cart after they start accelerating (if you need help, see section 4-6 and section 4-7 in chapter 4 of your text book). Check to see if any of these forces are related by Newton’s 3<sup>rd</sup> Law (Third Law Pairs). For easy reference, it is useful to draw the acceleration vector for the object next to its free-body diagram. It is also useful to put the force vectors on a separate coordinate system for each object (force diagram). Remember the origin (tail) of all vectors is the origin of the coordinate system. For each force diagram (one for the cart and one for object A), write down Newton’s 2<sup>nd</sup> law along each axis of the coordinate system. It is important to make sure that all of your signs are correct. For example, if the acceleration of the cart is in the + direction, is the acceleration of object A + or -? Your answer will depend on how you define your coordinate system.
5. Since you are interested in the velocity of the cart and the distance object A falls but Newton’s 2<sup>nd</sup> Law gives you an acceleration, write down any kinematic equations which are appropriate to this situation. You will have to decide if the acceleration of each object is constant or varies during the time interval for which your calculation is valid. What is that time interval?
6. You are now ready to plan the mathematics of your solution. Write down an equation, from those you have collected in steps 4 and 5 above, which relates what you want to know (the velocity of the cart just before object A hits the ground) to a quantity you either know or can find out (the acceleration of the cart and the time from the start until just before object A hits the floor). Now you have two new unknowns (acceleration and time). Choose one of these unknowns (for example, time) and write down a new equation (again from those collected in steps 4 and 5) which relates it to another quantity you either know or can find out (distance object A falls). If you have generated no additional unknowns, go back to determine the other original unknown (acceleration). Write down a new equation that relates the acceleration of the cart to other quantities you either know or can find (forces on the cart). Continue this process until you generate no new unknowns. At that time you should have as many equations as unknowns.

You can now solve your mathematics to give the prediction.

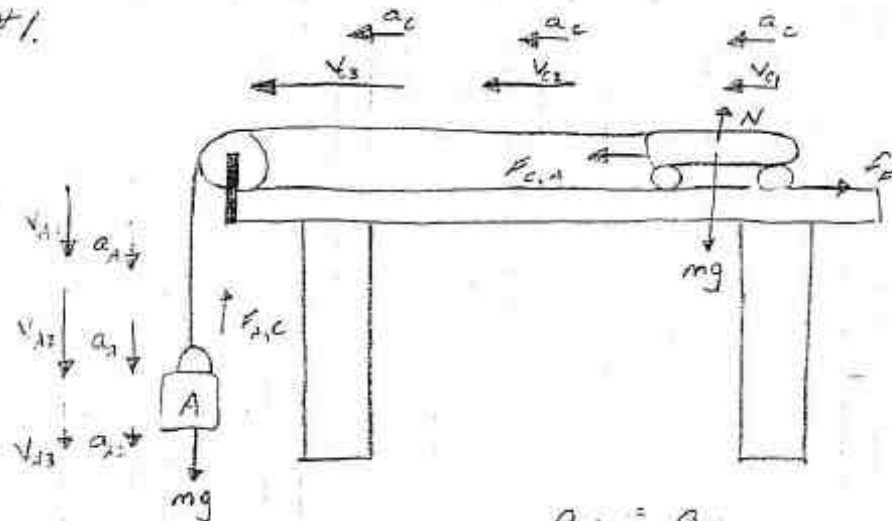
LAB III PROBLEM I

"Force and Motion"

Method Questions

Student #1

#1.

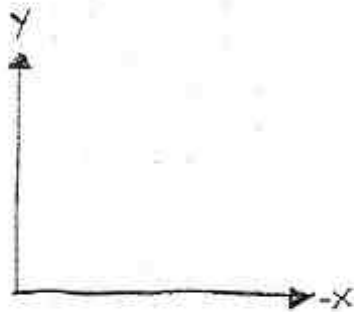


$$a_A = a_c$$

Acceleration of the mass A and the cart may be equal except when mass A hits the ground

$$v_A = v_c$$

velocity of the mass A and the cart may be equal except when the mass A hits the ground.



#2

Mass of object A =  $m_A$

Mass of the cart =  $m_c$

Height mass A is above ground =  $h$

Relationship

The velocity after object A hits the floor > The velocity just before object A hits the floor.

Unknowns

Velocity of cart and object A before it hits the ground

Acceleration of cart and object A

Coefficient of friction between the cart and track

#3. Physics to Use: Newton's laws  
 $F = ma$

May also need the equations for motion under constant acceleration:

$$x = x_0 + v_0 t + \frac{1}{2} a t^2$$

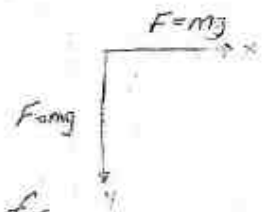
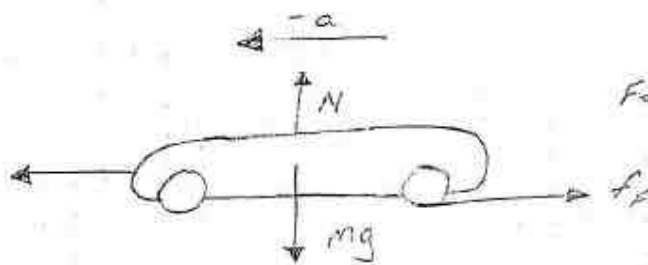
since object A is falling at a constant acceleration under gravity.

Student #1, p.2

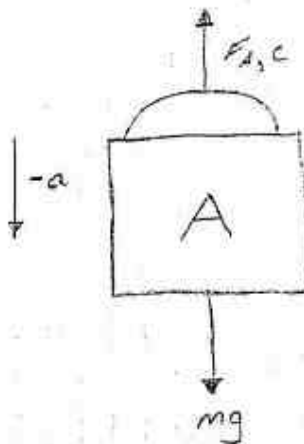
#4. FBD of the Cart



$F_{C,A}$



FBD of Object A



#5. Kinematic Equations to Use

$$v = at + v_0$$

$$x = x_0 + v_0 t + \frac{1}{2} a t^2$$

$$y = y_0 + v_0 t + \frac{1}{2} a t^2$$

\* If acceleration is constant

Time Interval:  
 Time object A is released from rest until it hits the ground

#6

Force of object A

$$F_A = m_A g$$

Student # 1, p. 3

\*  $F_A =$  Force of the cart due to object a ( $F_c$ )

Force of the cart

$$F_c = m_c a_c$$

so...  $m_c a_c = m_A g$

$$\rightarrow a_c = \frac{m_A g}{m_c}$$

\* Velocity of the cart just before object A hits ground

$$v_c = a_c t + v_0$$

$$v_c = \left( \frac{m_A g}{m_c} \right) t$$

• acceleration of the cart equals the mass of A times gravity divided by the mass of the cart

t = time it takes object A to reach the distance just above the ground

y Position of the object A

$$y = y_0 + v_0 t - \frac{1}{2} a_y t^2$$

$$0 = H - \frac{1}{2} g t^2$$

$$-H = -\frac{1}{2} g t^2$$

$$-\frac{1}{2} g \quad -\frac{1}{2} g$$

$$t^2 = \frac{H}{\frac{1}{2} g}$$

$$t = \pm \sqrt{\frac{2H}{g}}$$

Acceleration of the cart

$$a_c = \frac{m_A g}{m_c}$$

Velocity of the cart

$$v_c = \left( \frac{m_A g}{m_c} \right) t$$

Time to Fall

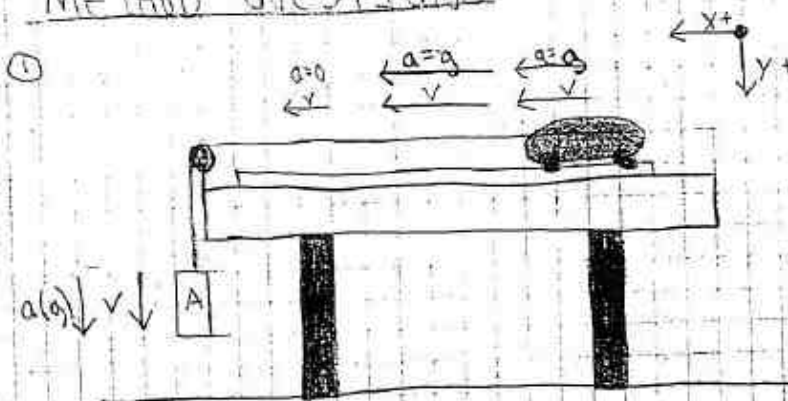
$$t = \sqrt{\frac{2H}{g}}$$

# LAB III PROBLEM #1

Student #2.

? What is the velocity of the car after being pulled for a certain distance.

## METHOD QUESTIONS



Object A falls with acceleration due to gravity. Therefore the acceleration of the cart is gravity, as well before object A hits the ground.

- ② mass of object A =  $m_A$   
mass of cart =  $m_C$   
height above floor A is released =  $h_{AO}$

unknowns:  $v_A$   
 $v_C$

the cart will have the same velocity just before and right after object A hits the ground.

- ③  $F = ma$   
 $F_{BA} = -F_{AB}$

I assume the object falls with gravity and that the cart will also move with the force of gravity.  
I assume air resistance and friction are negligible.

- ④ FBD  $F_N = -ma$



$F_N = -ma$





⑥  $x = x_0 + v_0 t + \frac{1}{2} a t^2$   
 $v^2 - v_0^2 = 2a(x - x_0)$   
 $v = v_0 + at$

Student # 2, p. 2

⑥  $v = v_0 + at$   
 $v = at$

$x = x_0 + v_0 t + \frac{1}{2} a t^2$   
 $x - x_0 = v_0 t + \frac{1}{2} a t^2$   
 $x = \frac{1}{2} a t^2$   
 $\frac{dx}{dt} = at$   
 $\sqrt{\frac{2x}{a}} = t$

$v = \left(\sqrt{\frac{2x}{a}}\right)(a)$

## PREDICTION

- calculate car's velocity after A hits floor as a function of the mass of A, mass of cart, and distance A falls.

$v = \left(\sqrt{\frac{2x}{a}}\right)(a)$

- graph cart's velocity after A hits floor as function of mass of A for some cart mass and height of A



- graph cart's velocity after A hits floor as function of mass of cart for same mass of A and height



- graph cart's velocity after A hits floor as function of distance A falls for same cart mass and mass



### LAB III Problem #1 Force and Motion

**Question** What is the velocity of the car after being pulled for a known distance?

**Equipment** cart, track, hanging object, string, meterstick, stopwatch, pulley w/ clamp, and video analysis equipment

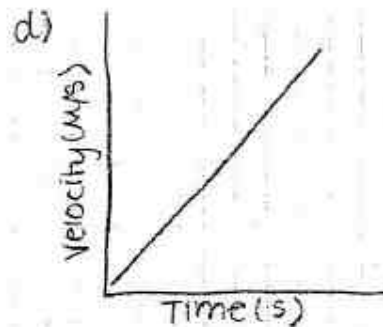
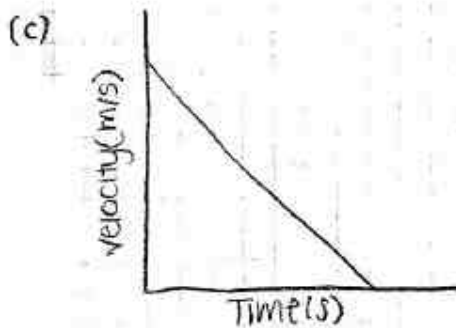
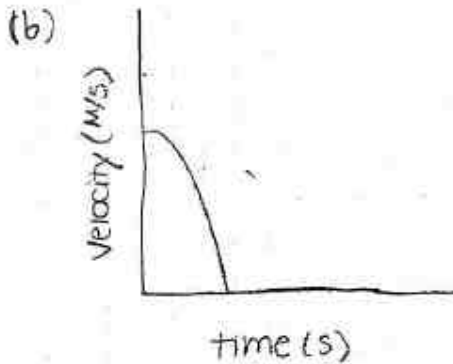
**Prediction**

Student #3

(a)  $a = F / (m_1 + m_2)$

$$v = \sqrt{\frac{2Fd}{m_1 + m_2}}$$

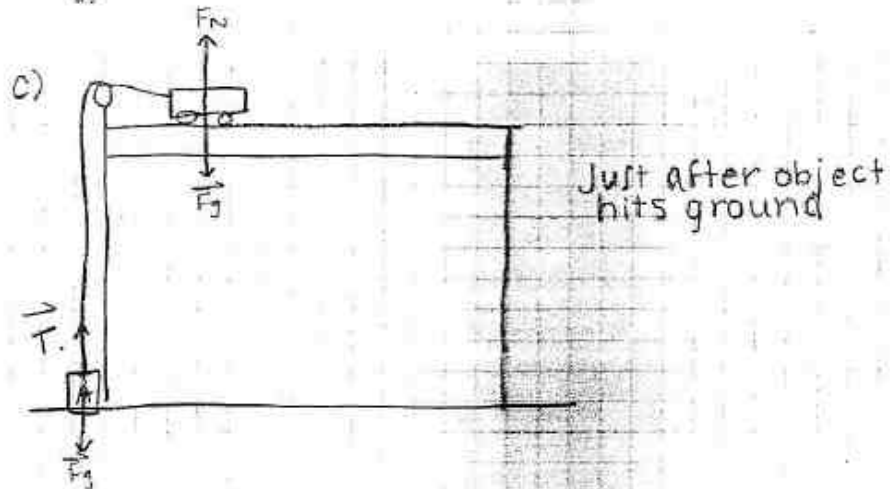
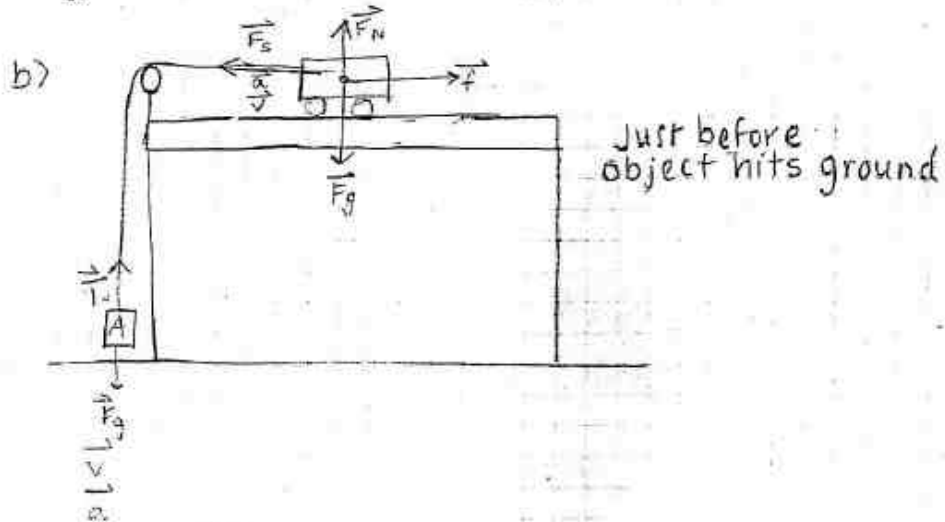
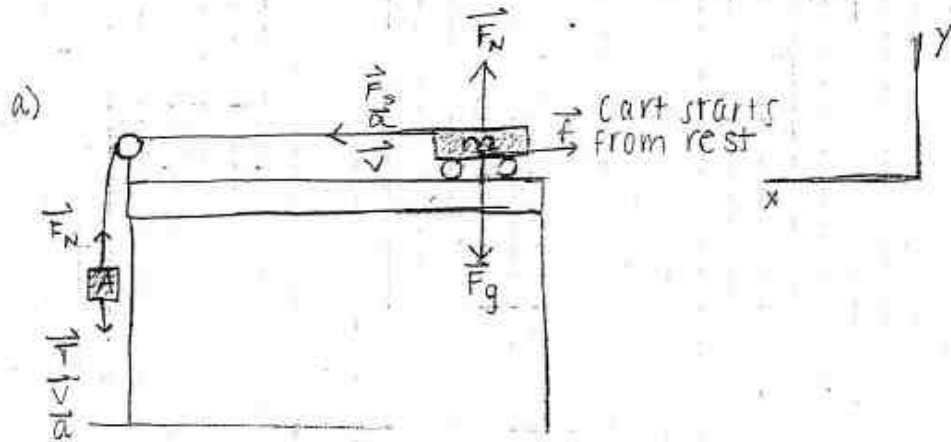
$m_1$   
 $m_2$   
 $d$



Method

Student #3, p.2

①



Student #3, p3

Known Quantities:

mass of "A"  $m_A$   
 mass of cart  $m_C$   
 height above floor where A is released  $h_A$

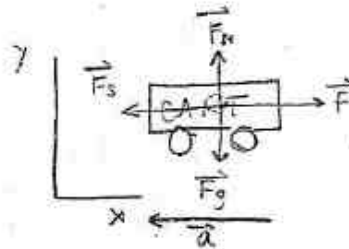
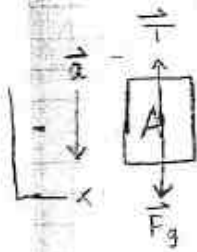
Knowns:

velocity of cart  $v_C$   
 velocity of A just before it hits floor  $v_A$   
 acceleration of cart  $a_C$

$$\vec{F}_{net} = m\vec{a} \quad \vec{F}_{net} = m \frac{d\vec{v}}{dt} \quad F_{x,net} = ma_x = m \frac{dv_x}{dt}$$

$$F_{y,net} = ma_y = m \frac{dv_y}{dt}$$

$$\vec{F}_{BA} = -\vec{F}_{AB}$$



$$x(t) = x_0 + v_{0x}t$$

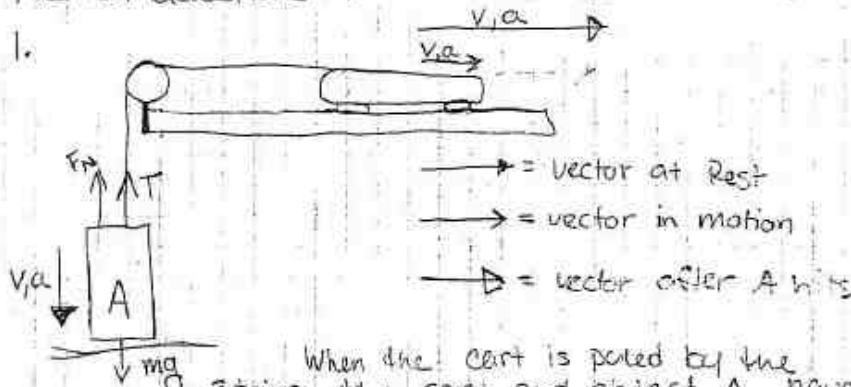
$$v(t) = v_0 + v_{0y}t$$

# Lab III: Forces

Student #4

## Method Questions

1.



When the cart is pulled by the string, the cart and object A have the same magnitude of velocity because as object A falls, the string pulls the cart.

2. Mass of object A =  $m_a$   
 height above the floor in beginning =  $h_0$   
 Mass of cart =  $m_c$

Unknowns:

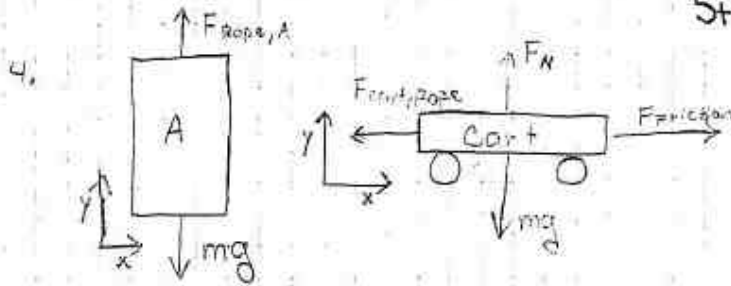
- Velocity of cart before A hits ground
- Velocity of object A just before hitting the ground

The velocity of the cart when it is released will equal the velocity of object A just before hitting the ground.

3.  $F = m_a a$        $F_{Ac} = -F_{cA}$

The velocity of the cart is equal to the velocity of the object A

Student #4, p. 2



if the acceleration of A is (-) the acceleration of the cart is (+)

$$5. v_f^2 = v_i^2 + 2\Delta y a$$

$$6. v_f^2 = v_i^2 + 2 \Delta y a$$

velocity @ Start

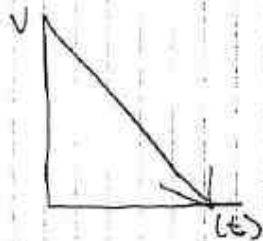
displacement of object

$$x(t) = x_0 + v_0 t + \frac{F}{2m} t^2$$

$$a = m/E$$

Predictions:

$$v_c = v_a \quad m_c \frac{dv}{dt} = m_a \frac{dv}{dt}$$



PREDICTION:

$v_{cart} = v_{weight}$        $d_{weight} = \frac{1}{2}gt^2$   
 $a_{cart} = a_{weight}$   
 $d_{weight} = d_{cart}$

$$v_{cart} = \frac{m_w(d_{sw}) - v_i t}{m_{cart} + t}$$

Student # 5

Method & S:

1)

2)

3)

The  $v$  and  $a$  of the cart should be equal, since the tension of the string would transmit the force without any loss.

2)  $m_{cart} + m_c = m_w$  mass of cart =  $m_w$  mass of weight =  $m_w$  height of weight =  $d_w$   
 unknowns:  $a$  acels of cart and weight, dist cart travels

They should be the same, since the cart is no longer accelerating after the object hits the ground.

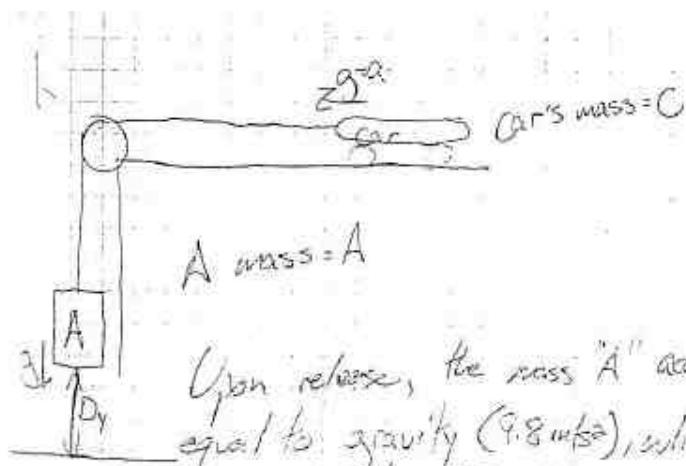
$F = ma$ ,  $F_{BA} = -F_{AB}$ ,  $v = v_0 + \frac{1}{2}at$  assume  $a = -g$  since object falls toward ground, and the  $F_{10} = \frac{1}{2}F_0$ , dec to 3rd law of motion

Student # 5  
 p. 2

$v = v_0 + \frac{1}{2}at$ , the time interval is the period from the moment both object and cart begin to accelerate to right before the mass hits the ground -  $d = v_0t + \frac{1}{2}at^2$

6)  $v = \frac{F \cdot T}{m_{car}}$      $F = mca$      $v = \frac{(mca) \cdot T}{m_w}$      $v = \frac{\sqrt{2(m_w \cdot d)}}{m_c \cdot t}$      $\frac{\sqrt{2(d)}}{a}$





Student #6

A mass = A

Upon release, the mass "A" accelerates at a value equal to gravity (9.8 m/s<sup>2</sup>), which in turn accelerates the car at 9.8 m/s<sup>2</sup>. So, we can find the car's velocity at a given time using the derivative of the position formula, aka, the velocity formula

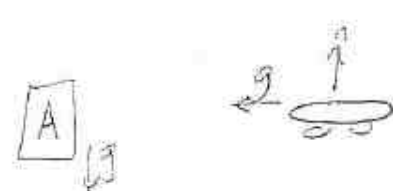
$$p_x(t) = x_0 + v_0 t + \frac{1}{2} a t^2$$

$$v_x(t) = v_0 + a t$$

Newton's 2ND Law  $F = ma$

- Known
- $x_0 = 0$
  - $v_0 = 0$
  - $a = 9.8 \text{ m/s}^2$
  - mass A = A
  - mass car = C
  - distance between A and floor =  $D_y = \frac{1}{2} g t^2$
- Unknown
- $v_x(t)$
  - $v_y(t)$

4.



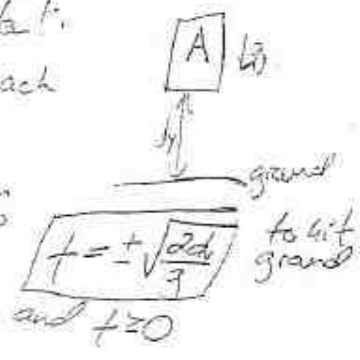
5. The acceleration (g) is constant.  
The time (t) for A to reach the ground is equal to:

so

$$p(t) = -d_y + v_0 t + \frac{1}{2} a t^2$$

$$0 = -d_y + \frac{1}{2} g t^2$$

$$d_y = \frac{1}{2} g t^2, \quad t = \frac{2d_y}{g}$$



Prediction

Student #6, p 2

Carts velocity after A hits floor

$$px = x_0 + v_0t + \frac{1}{2}at^2$$

$$t = \sqrt{\frac{2x}{g}}$$

$$px = \frac{1}{2}gt^2$$

$$a = g = 9.8 \text{ m/s}^2$$

$$x_0 = 0$$

$$v_0 = 0$$

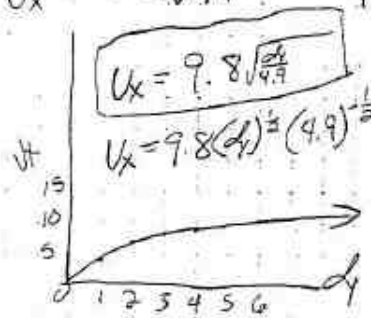
$$v_x = gt$$

$$v_x = 9.8 \cdot \sqrt{\frac{2x}{g}}$$

$$v_x - v_0 = gt$$

$$v_x = 9.8 \sqrt{\frac{2x}{9.8}}$$

Since the cart and mass A are connected, their velocities, accelerations, etc. up until A reaches the floor will be the same.



- $v_x(0) = 0$
- $v_x(1) = 4.42$
- $v_x(2) = 6.26$
- $v_x(3) = 7.66$
- $v_x(4) = 8.85$
- $v_x(4.9) = 9.8$
- $v_x(5) = 9.9$
- $v_x(6) = 10.84$

**Lab Preparation**

Name: \_\_\_\_\_

Date: \_\_\_\_\_

Lab Problem: \_\_\_\_\_

Section \_\_\_\_\_

I. Solve the problem yourself by answering the Warm-up questions. Then read the **Lab Instructor's Manual**. Finally, grade the Warm-up Questions for this section.

II. Answer the following background questions.

<p><b>1</b> When is session scheduled?</p>	<p><b>2</b> Which session is it in the Lab topic sequence?</p>	<p><b>3</b> What is the lab problem type?</p>	<p><b>4</b> How difficult is the lab problem?</p>
<p><input type="checkbox"/> Early in Week <input type="checkbox"/> Later in Week</p>	<p><input type="checkbox"/> 1<sup>st</sup> Lab Session <input type="checkbox"/> 2<sup>nd</sup> or 3<sup>rd</sup> Lab session</p>	<p><input type="checkbox"/> Qualitative <input type="checkbox"/> Quantitative</p>	<p><input type="checkbox"/> Easy/Medium <input type="checkbox"/> Difficult</p>
<p><b>5</b> Which of the WUQs did your students have the most difficulty answering? Common alternative conceptions? Which ones?</p>		<p>Warm-up Questions: _____</p>	
<p><b>6</b> Count the number of students who were able to solve the problem (even if the solution was incorrect). Is this the majority of the students?</p>		<p>_____ students solved the problem out of _____.</p>	
<p><b>7</b> Look at the students' final solution (Prediction). How many students got the right answer for the wrong reasons?</p>		<p>_____ students got the right (or close to right) answer for the wrong reasons.</p>	

III. Based on the answers to these questions, make the following decisions about opening moves and the end game for the lab session.

Opening Moves		
<p>1. Which WUQs should I assign groups answer on board?</p>	<p>Use answer to Question <b>5</b>:</p>	<p>Warm-up Questions: _____</p>
<p>2. Do groups need extra time to solve the problem before they start collecting data?</p>	<p>Use answer to Question <b>6</b>, taking into account Questions <b>1</b> to <b>4</b></p>	<p><input type="checkbox"/> YES <input type="checkbox"/> NO because:</p>
<p>3. If YES, then how much time extra time and how should I structure this extra time?</p>	<p>Use answers to Questions <b>1</b> to <b>4</b></p>	<p>Plan:</p>
<p>4. What do I need to discuss/tell students about how to check their solution before they start?</p>	<p>Use information in <i>Lab Instructor's Guide</i> and your own experience</p>	<p>Discuss:</p>

End Game		
5. (Besides corrected answers to assigned WUQs), do we need to spend extra time discussing how to solve the problem?	Use answer to Question 7 and your previous decisions 2 & 3	<input type="checkbox"/> YES <input type="checkbox"/> NO because:
6. If YES, then how much time and how should I structure this extra time?		Plan:

IV. List some possible questions to ask groups during whole-class discussion (opening moves and/or end game) that you think would promote a discussion.

a.
b.
c.
d.
e.
f.
g.