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:
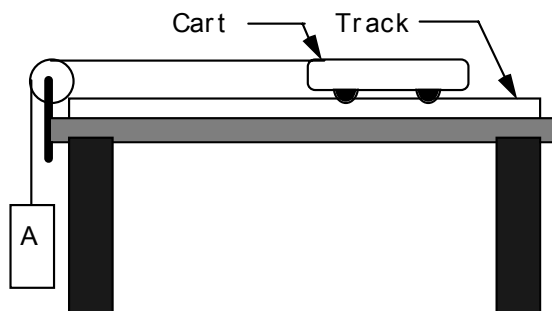
You will be able to vary the mass of Object A (the "mass hanger") and the Cart. They are connected together using a light string. Object A falls through a distance which is significantly shorter than the length of track. You will have a meter stick, a stopwatch, a mass hanger, a mass set, cart masses, 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 <u>after object A has hit the floor</u>, 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 <u>after object A has hit the floor</u>, 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 <u>after object A has hit the floor</u>, 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 <u>after object A has hit the floor</u>, 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 2nd 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 3rd 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 3rd 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 2nd 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 2nd 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.
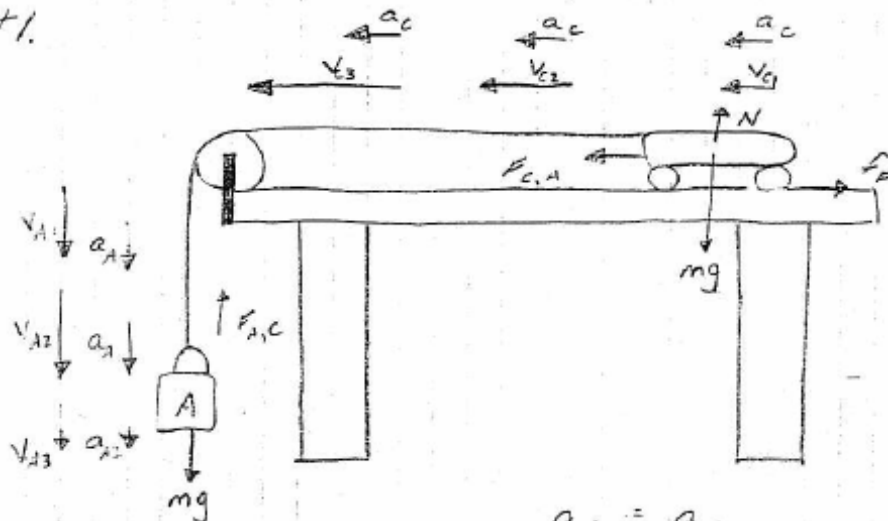
You can now solve your mathematics to give the prediction.

LAB III   PROBLEM I
"Force and Motion"   Student #1

Method Questions

#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: Newtons Laws

$$F = ma$$

May Also need the equations for motion
under constant acceleration:

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

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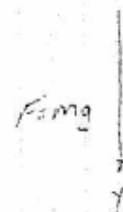acceleration under gravity.

Student #1, p.2

#4.   FBD of the Cart
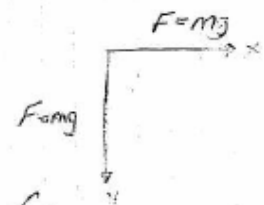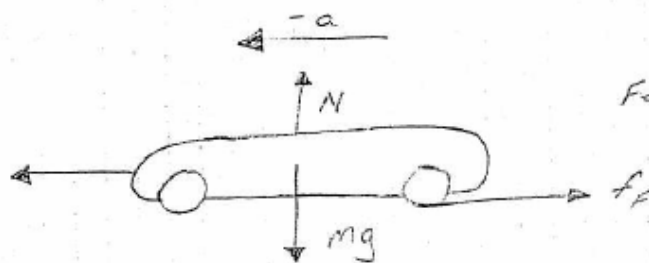
FBD of Object A
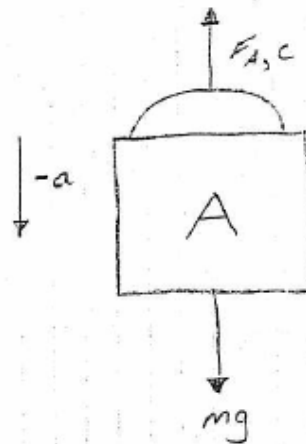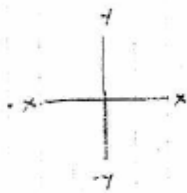
#5.   Kinematic Equations to Use:

$$v = at + v_0$$

* If acceleration $x = x_0 + v_0 t + \tfrac{1}{2} a_x t^2$
is constant $y = y_0 + v_0 t + \tfrac{1}{2} a_y t^2$

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

#6.

$$\underline{\text{Force of object } A}$$

$$F_A = m_A g$$

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

Student #1, p.3

$$\underline{\text{Force of the cart}}$$

$$F_c = m_c a \qquad \text{So...} \qquad m_c a_c = m_A g$$

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

→ Velocity of the cart
just before object A hits ground

$$V_c = a_c t + V_o$$

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

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

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

Y Position of the
object A.

$$Y = Y_o + V_o t - \tfrac{1}{2} a_y t^2$$

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

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

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

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

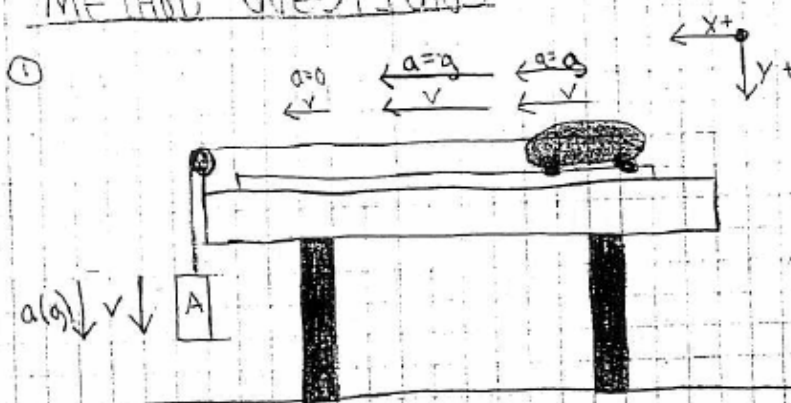$$t^2 = \frac{-H}{-\tfrac{1}{2} g}$$

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

LAB III
PROBLEM #1   Student #2.

[?] What is the velocity of the car after being pulled
for a known distance.

METHOD QUESTIONS

① Object A falls with acceleration due to gravity.
Therefore the acceleration of the car 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_{A0}

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 negligable.

④ FBD $F_N = -ma$ $F_N = -ma$

⑤ $x = x_0 + V_0 t + \frac{1}{2} a t^2$
   $V^2 - V_0^2 = 2a(x - x_0)$
   $V = V_0 + at$

Student #2, p.2

⑥ $V = V_0 + at$ $x = x_0 + V_0 t + \frac{1}{2} a t^2$
   $V = at$ $x - x_0 = V_0 t + \frac{1}{2} a t^2$
                          $x = \frac{1}{2} a t^2$
                          $2x = a t^2$
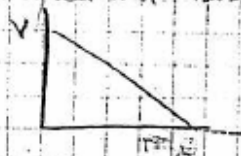 $\sqrt{\frac{2x}{a}} = t$
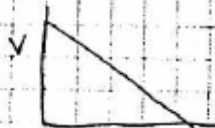
$V = \left(\sqrt{\frac{2x}{a}}\right)(a)$

PREDICTION

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

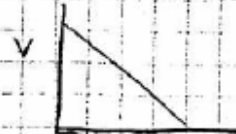$$V = \left(\sqrt{\frac{2x}{a}}\right)(a)$$

- graph cart's velocity after A hits floor as function of mass of A for same 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 carts 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 bei
pulled for a known distance?

[Equipment] Cart, track, hanging object, string, meterstick,
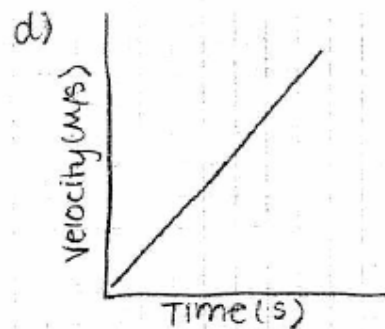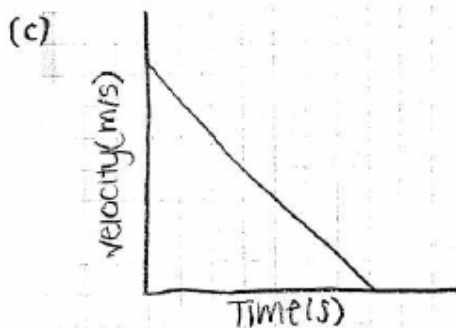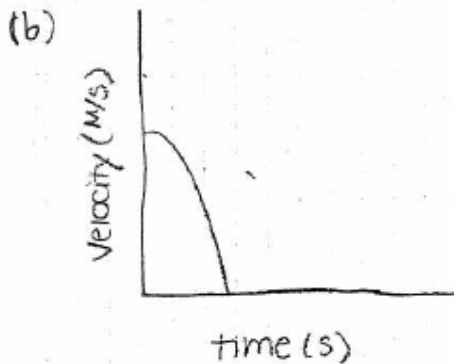stopwatch, pulley w/ clamp, and video
analysis equipment

[Prediction]

Student #3

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

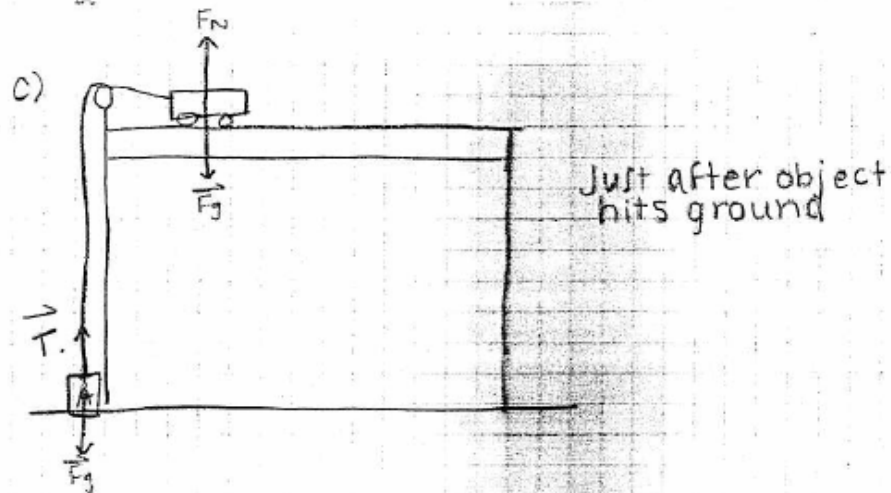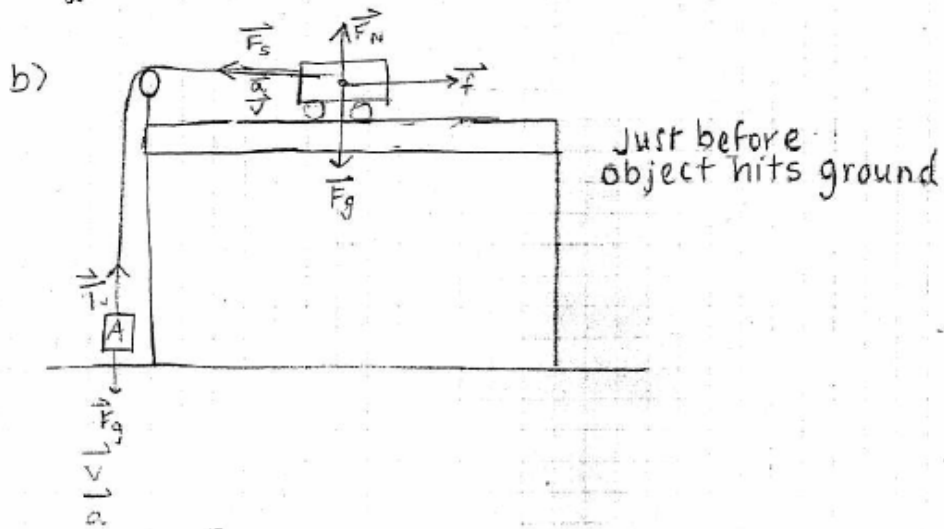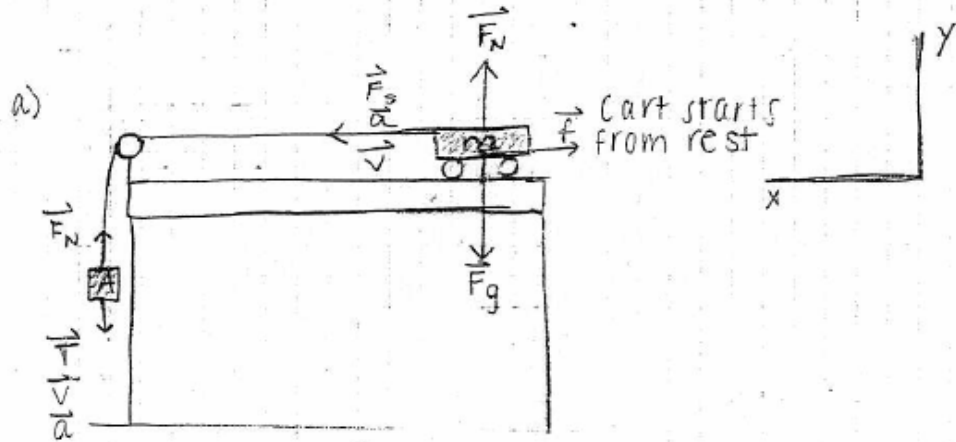 $V = \sqrt{\dfrac{2Fd}{m_1+m_2}}$

       m_1
       m_2

       d

(b)

(c)

d)

method

①

Student #3, p.2

a)

$\vec{F_N}$

$\vec{F_s}$
$\vec{a}$

Cart starts from rest

$\vec{f}$

y

$\vec{v}$

x

$\vec{F_N}$

A

$\vec{F_g}$

$\vec{T}$ $\vec{v}$ $\vec{a}$

b)

$\vec{F_s}$
$\vec{a}$
$\vec{v}$

$\vec{F_N}$

$\vec{f}$

Just before object hits ground

$\vec{F_g}$

$\vec{T}$

A

$\vec{F_g}$ $\vec{v}$ $\vec{a}$

c)

$\vec{F_N}$

Just after object hits ground

$\vec{F_g}$

$\vec{T}$

A

$\vec{F_g}$

Student #3, p 3

Known Quantities:
  mass of "A" m_A
  mass of cart m_C
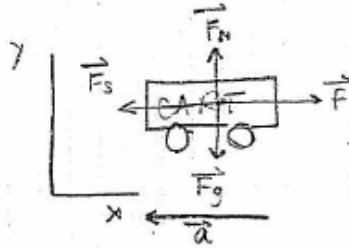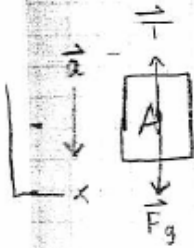 height above floor where A is released h_A

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

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

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

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

$x(t) = x_0 + v_{ox}t$
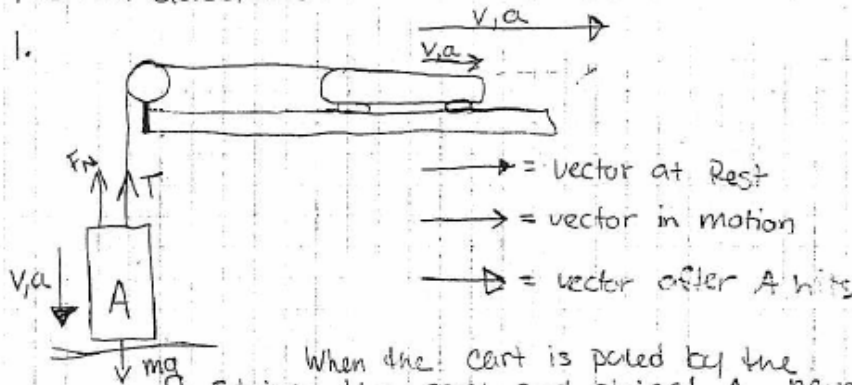$v(t) = v_0 + v_{oy}t$

Lab III : Forces

Method Questions

Student #4

1.

→ = vector at Rest

→ = vector in motion

▷ = vector after A hits

When the cart is puled 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 begining = h_0
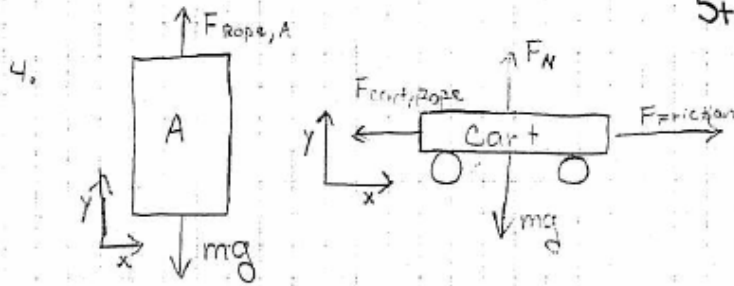   Mass of cart = m_c

    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. $F = ma$ $F_{Ac} = -F_{cA}$

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

Student #^{4}, p. 2

4.

$\uparrow F_{Rope,A}$

A

$\downarrow mg$

$F_{cart,rope}$ $\uparrow F_N$

Cart $\rightarrow F_{friction}$

$\downarrow mg$

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

5. $V_f^2 = V_i^2 + 2\Delta y \alpha$
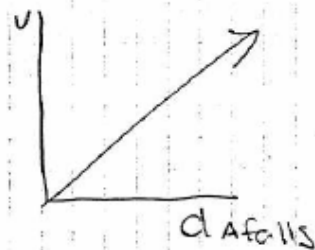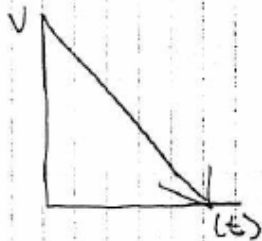
6. $V_f^2 = V_i^2 + 2\Delta x \alpha$

velocity @ start

displacement of object

$X(t) = X_0 + V_{0x}t + \frac{F}{2m}t^2$

$a = {}^m/_F$

Predictions:
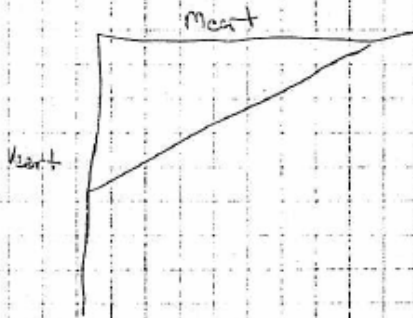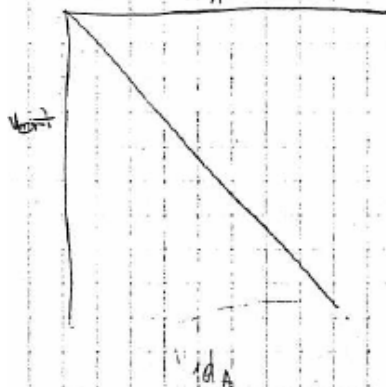
$V_c = V_a$ $m_c \frac{dv}{dt} = m_a \frac{dv}{dt}$

V

(t)

V

d A falls

PREDICTION:

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

$V_{cart} = V_{weight}$

$d_{sweight} = d_{cart}$

$$V_{cart} = \frac{m_w (d_{sw}) - \frac{1}{2}t}{m_{cart} \cdot t}$$

Student (# 5)

Method $\varnothing$'s:

1) $V_i = -\frac{1}{2}gt$
        $a = -g$
$V = -gt$
$a = -g$

2     $V = \frac{1}{2}gt$
$V = -\frac{1}{2}gt$
$a = g$

3     $\frac{V_1}{a=0} \frac{V_2}{}$
$V = 0$
$a = 0$
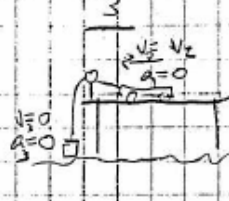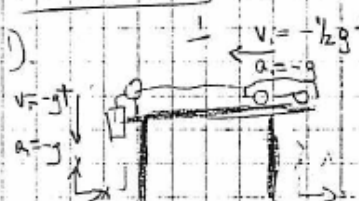
The v and a of the cart should be equal, since the tension of the string would transmit the force without any loss

2) mass of cart = m_c mass of weight = m_w height of weight = d_w
    unknowns: accels 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.

) $\vec{F} = ma$ | $\vec{F}_{BA} = -\vec{F}_{AB}$ $v = v_0 + \frac{1}{2}at$ assume $a = -g$ since object falls toward ground, and the $F_m = -F_c$, due 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. $d = d_0 + v_0 t + \frac{1}{2}at^2$

5) $v = \dfrac{F \cdot T}{m_{cr}}$ $\vec{F} = m_c a$ $v = \dfrac{(m_c a) \cdot T}{m_w}$ $v = \sqrt{\dfrac{2(m_w \cdot d)}{m_c \cdot t}}$ $\sqrt{\dfrac{2(d)}{a}}$

1.

$z \overset{a}{\overset{g}{\longrightarrow}}$

Car's mass = C

Student #6

A mass = A

$D_y \downarrow$
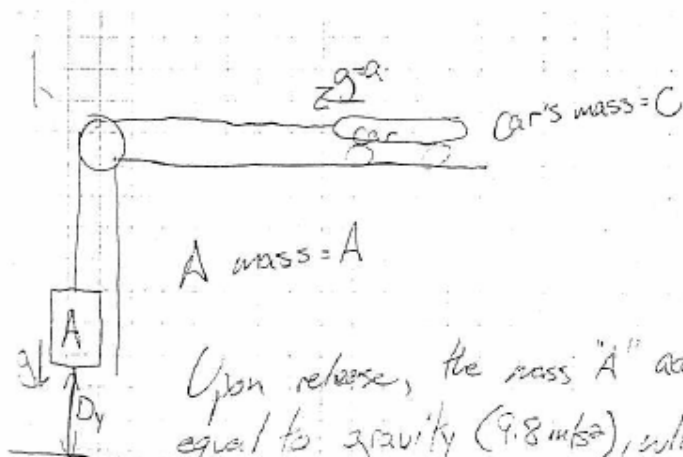
Upon release, the mass "A" accelerates at a value equal to gravity ($9.8 \, m/s^2$), which in turn accelerates the car at $9.8 \, m/s^2$. So, we can find the cars velocity at a given time using the derivative of the position formula, aka. the velocity formula.

$$P_x(t) = x_0 + v_0 t + \tfrac{1}{2} a t^2$$
$$v_x(t) = v_0 + a t$$

Newton's 2ND Law $F = ma$

Known
$x_0 = 0$
$v_0 = 0$
$\boxed{a = 9.8 \, m/s^2}$

mass A = A

mass car = C
distance between A and floor = $\boxed{D_y = \tfrac{1}{2} g t^2}$

Unknown
$v_c(t)$
$v_A(t)$

4.

$\boxed{A} \, \downarrow g$

$\overset{\uparrow}{\underset{\frown}{\longleftarrow} g}$

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

$\boxed{A} \, \downarrow g$
$\uparrow$
———— ground

$$P_y(t) = -d_y + v_0 t + \tfrac{1}{2} a t^2 \text{ when}$$

so
$$0 = -d_y + \tfrac{1}{2} g t^2 \qquad v_{0y} = 0$$
$$P_y(t) = 0$$
$$d_y = \tfrac{1}{2} g t^2, \quad t^2 = \tfrac{2d_y}{g} \qquad a = g$$
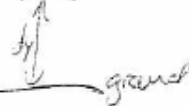
$$\boxed{t = \pm \sqrt{\tfrac{2d_y}{g}}} \quad \text{to hit ground}$$
$$\text{and } t \geq 0$$

Prediction　　　　　　　　　　　　　　　　　　Student #6., p 2

Carts velocity after A hits floor

$P_x = x_0 + v_0 t + \frac{1}{2} a t^2$,　　　　　$t = \sqrt{\frac{2d}{g}}$
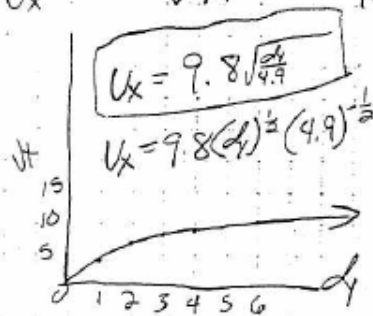
$P_x = \frac{1}{2} g t^2$　　　　　　　　　$a = g = 9.8 m/s^2$

　　　　　　　　　　　　　　　　$x_0 = 0$

$v_x = g t$　　　　　　　　　　$v_0 = 0$

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

Since the cart and mass A

$\boxed{v_x - v_0 = g t}$　　are connected, their velocities,
　　　　　　　　　　accelerations, etc. up until A reaches
$v_x = 9.8 \sqrt{\frac{d}{4.9}}$　　the floor will be the same.

$\boxed{v_x = 9.8 \sqrt{\frac{d}{4.9}}}$　　$v_x(0) = 0$
　　　　　　　　　　$v_x(1) = 4.42$
$v_x = 9.8 (d)^{\frac{1}{2}} (4.9)^{-\frac{1}{2}}$　　$v_x(2) = 6.26$
　　　　　　　　　　$v_x(3) = 7.66$
　　　　　　　　　　$v_x(4) = 8.85$
　　　　　　　　　　$v_x(4.9) = 9.8$
　　　　　　　　　　$v_x(5) = 9.9$
　　　　　　　　　　$v_x(6) = 10.84$

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.

❶ When is session scheduled?	❷ Which session is it in the Lab topic sequence?	❸ What is the lab problem type?	❹ How difficult is the lab problem?
☐ Early in Week ☐ Later in Week	☐ 1st Lab Session ☐ 2nd or 3rd Lab session	☐ Qualitative ☐ Quantitative	☐ Easy/Medium ☐ Difficult
❺ Which of the WUQs did your students have the most difficulty answering? Common alternative conceptions? Which ones?	Warm-up Questions: _____		
❻ 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?	____ students solved the problem out of ____.		
❼ Look at the students' final solution (Prediction). How many students got the right answer for the wrong reasons?	____ students got the right (or close to right) answer for the wrong reasons.		

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		
1. Which WUQs should I assign groups answer on board?	Use answer to Question ❺:	Warm-up Questions: _____
2. Do groups need extra time to solve the problem before they start collecting data?	Use answer to Question ❻, taking into account Questions ❶ to ❹	☐ YES ☐ NO because:
3. If YES, then how much time extra time and how should I structure this extra time?	Use answers to Questions ❶ to ❹	Plan:
4. What do I need to discuss/tell students about how to check their solution before they start?	Use information in *Lab Instructor's Guide* and your own experience	Discuss:

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 ❼ and your previous decisions 2 & 3	☐ YES ☐ 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.