5.9: Force and Motion I

Name: ____

Date: ______________________

Partners:____

Equipment

• *LabPro* Interface • Motion detector • Force sensor • *Force* software file	• Dynamics track • Dynamics cart • Pulley • Hanging masses

Introduction

The force sensor is a device that measures the amount of force applied to the hook attached to the sensor. The sensor can only measure the force component applied parallel to its length, and forces directed away from the sensor are typically regarded as positive.

The force sensor measures force by means of a strain gauge. As a force is applied to the sensor, a small metal bar inside the sensor deforms. Strain gauges attached to the bar change resistance as the bar deforms. This change in resistance results in a change in voltage. In order to convert this voltage information into force information, the sensor must be calibrated.

The sensor is calibrated by means of a *two-point calibration*. First, no force is applied to the sensor and the resulting voltage is recorded. Then a known force is applied and the resulting voltage recorded. Using these two points as reference, and assuming a linear relationship between force and voltage, any voltage reading can be converted into a force reading. Since the force sensor is accurate enough to detect the weight of the hook, it should always be calibrated in the same orientation in which it will be used.

In this activity, you will measure both the motion of a cart using the motion detector and the force applied to the cart using the force probe. The relationship between the force acting on an object and its subsequent motion is of central importance in many branches of physics.

I. Calibrating the Force Sensor

Open the file *Force.*

Set the sensor to the ±10 N setting and securely attach it to the top of the cart. Place the cart at rest on the track.

To calibrate the force sensor, select **Experiment/Calibrate** and select the Force sensor. Select **Calibrate Now**. You will perform a two-point calibration of the sensor:

- For the first calibration point, do not apply any force to the sensor, enter 0 N, and hit **Keep.**
- For the second calibration point, attach a 200 g mass to the sensor by means of a string passing over the pulley. Enter the force of gravity acting on this mass (1.96 N) and hit **Keep.**

The sensor is now calibrated.

To check the calibration of the sensor, complete the following table. In each case, attach the appropriate hanging mass, hold the cart at rest, and collect force data for several seconds. Find the mean and standard deviation of the force sensor data.

Hanging Mass (g)	Weight (N)	Mean Sensor Reading (N)
0		±
50		±
100		±
150		±

200		±
500		±

You are now going to create a graph, with error bars, of Weight vs. Mean Sensor Reading. To do this in *LoggerPro*:

- Select **Insert/Table** to view your data table. Find the empty columns labeled y-axis, delta y, x-axis, delta x. (The other columns are filled with the last set of data you collected. You can delete or just ignore this data.)
- Enter your data into the appropriate column. (Weight on the y-axis, sensor reading on the x-axis, and the uncertainty in sensor reading as delta x.)
- Double-click on each column header to change the label and units for each column.
- Create a graph of Weight vs. Mean Sensor Reading by changing the variables on the x- and y-axis of one of your pre-existing graphs.
- Right-click on the graph, select **Graph Options/Graph Options**, and deselect the option **Connect Points**.
- Based on your data, select an appropriate best-fit function (**Analyze/Linear Fit** or **Curve Fit**) and display it on your graph. Remember, a best-fit function should be the *simplest possible function* that accurately matches your data.

Finish preparing your graph, then print and attach it to the end of this activity.

Question: Record each constant in your best-fit function below. Each numerical value must have both uncertainties and units. (To determine the uncertainties in linear fit parameters, right-click in the Linear Fit box and select **Linear Fit Options**. This displays the standard deviation of the slope and y-intercept.)

Question: If the force sensor accurately measures the force applied to it, what should the slope and y-intercept of your best-fit function equal? Explain.

Question: Does your force sensor accurately measure the force applied to it? Explain.

II. Force and Initial Motion

Display graphs of force and acceleration vs. time.

Attach 200 g to the sensor via a string passing over the pulley. Hold the cart in place about 20 cm in front of the motion detector, press **Collect**, and after about 1 second of data collection release the cart. Make sure that the track is clean, the wheels of the cart turn freely, and the force sensor cord does not drag behind the cart.

Once you have recorded a clean run of the experiment, properly prepare and print your graph and attach it to the end of this activity. Draw a vertical line (through both graphs) at the time you released the cart. Label the line "*Release*".

Question: Your force vs. time graph should show a clear decrease in force when you released the cart. Is this decrease in force *real* (meaning the force applied to the cart actually does decrease when the cart is released) or is it a *glitch* (due to an imperfect measuring device)? If it is real, explain why the force suddenly decreases. If it is a glitch, hypothesize what is wrong with the measuring device.

Question: If the hanging mass was less massive, would the discontinuity in force be larger or smaller in magnitude? Explain.

Test your prediction by using a smaller magnitude hanging mass. ***Do not proceed until you understand the nature of the discontinuity in the force vs. time graph.***

III. Force and Acceleration

Using the hanging masses listed below, release the cart from rest and measure the mean force acting on the cart (after release) and the mean acceleration of the cart. Make sure that your data is clean and accurate before analyzing it, and only analyze the appropriate portion of the data. ***You must analyze the same time interval on both graphs.***

Print out and attach one of your trials with the region analyzed highlighted and the relevant statistics displayed. ***Show this graph to your instructor to verify that you are analyzing the data correctly!***

If at any time you believe your force sensor is producing erroneous readings, simply check the calibration by hanging a known weight from the sensor. Occasionally the sensor can "drift". This can be corrected by re-zeroing the sensor using the **Zero** button on the toolbar. If the readings are substantially off, you may need to re-calibrate your sensor.

Hanging Mass (g)	Mean Force (N)	Mean Acceleration ()
200	±	±
150	±	±
100	±	±
50	±	±

Create a graph, with error bars for both the y- and x-data, of Mean Force vs. Mean Acceleration. (**Insert/Table** to view your data table and simply "type-over" your previous inputted data. Remember to change the labels and units for each column.)

Based on your data, select an appropriate best-fit function (**Analyze/Linear Fit** or **Curve Fit**) and display it on your graph. Remember, a best-fit function should be the *simplest possible function* that accurately matches your data.

Finish preparing your graph, then print and attach it to the end of this activity.

Question: Record each constant in your best-fit function below. Each numerical value must have both uncertainties and units. (To determine the uncertainties in linear fit parameters, right-click in the Linear Fit box and select **Linear Fit Options**. This displays the standard deviation of the slope and y-intercept.)

Applying Newton's Second Law to the cart in the direction of motion results in:

Rearranging this equation results in:

Question: Your graph involved the force of the string on the y-axis and the acceleration of the cart on the x-axis. Based on this observation, and a simple comparison between your best-fit function and Newton's Second Law, what is the combined mass of your cart and sensor (with units and uncertainties) and what is the mean frictional force acting on your cart (with units and uncertainties)? How did you determine these values?

Question: Using a scale, determine the combined mass of your cart and sensor and record it below. Compare this value to the value determined above. Comment on the accuracy of your experimental data.

IV. Mass and Acceleration

In the previous activity, the force applied to the cart was varied and the mass of the cart was held constant. In general, it's a good idea to vary as few parameters as possible when conducting an experiment. In this experiment, you will hold the force constant while you vary the mass.

This is slightly more difficult since, as you saw earlier in this activity, the force applied to the cart is not equal to the weight of the hanging mass. Therefore, *even if the hanging mass is held constant, the force it exerts on the cart will not be constant*.

For example, if we consider the cart as the system of interest (as we did in the previous activity), the force sensor measures the force applied to the cart, but this force is not equal to the weight of the hanging mass.

Ffriction

$F_{friction}$

$F_{string} \neq 1.96$ N

$F_{string} \neq 1.96$ N

However, if we consider the cart and hanging mass together as the system of interest, the force applied to the system *is* equal to the weight of the hanging mass, which is easy to keep constant. Notice, for this system, that the force sensor doesn't measure anything useful! The two forces acting on the system are the weight of the hanging mass and the friction on the cart. This is the system we will experiment with below.

Ffriction

$F_{friction}$

$F_{gravity} = 1.96$ N

$F_{gravity}$ = 1.96 N

Using a 200 g hanging mass, collect data to complete the table below. Begin with a system of cart, sensor and 200 g hanging mass. Then, continually add 500 g to the system to complete the experiment. Make sure that your data is clean and accurate before analyzing it, and only analyze the appropriate portion of the data.

System	**System Mass (kg)**	**Mean Acceleration ()**
cart, sensor, 200 g		±
+500 g		±
+500 g		±
+500 g		±
+500 g		±

Create a graph of System Mass vs. Mean Acceleration. Include the uncertainty in the mean acceleration.

Based on your data, select an appropriate best-fit function (**Analyze/Linear Fit** or **Curve Fit**) and display it on your graph. Remember, a best-fit function should be the *simplest possible function* that accurately matches your data. Additionally, since you know this motion is governed by Newton's Second Law, your best-fit function should agree with Newton's law in functional form.

Question: Starting from Newton's Second Law applied in the direction of motion of the system, rearrange Newton's Law until mass is isolated on the left-side of the equation. (Your best-fit function should have this form.)

Print your graph with best-fit function displayed and attach it to the end of this activity.

Question: Record each constant in your best-fit function below, with units and uncertainties.

Question: Based on your best-fit function, what is the net force (with units and uncertainty) that acts on the system?

Question: Based on your best-fit function, and the observation that you used a 200 g hanging mass to accelerate the system, what is the mean frictional force (with units and uncertainty) that acts on the system? Is this value the same as in the previous experiment? Should it be? Carefully explain.