Newton's 2nd Law

Equipment Capstone, motion sensor, meter stick, force sensor, bench clamp, rod for force sensor, weights with hooks, 18.7 cm glider, 28.7 cm glider, air track, photogate/smart pulley, string for gliders, photo gate, large picket fence, digital scale, index cards, and small table clamp.

Photogate Sensor A digital sensor shaped in the form of a U. An infrared beam (peak at 880 nm) is passed between the legs of the U. With the beam unblocked the output of the sensor is high. With the beam blocked the output is low and a light on the sensor is on. Usually Capstone starts timing with a 10 kHz clock when the beam is blocked and stops timing when the beam is unblocked. This sequence is repeated if the beam is alternately blocked and unblocked. When used with various accessories such as picket fences and pulleys Capstone can calculate position, speed, acceleration, rotation, etc.

Force Sensor A analogue sensor that measures force in newtons (N) by means of a strain gauge. This sensor has a hook that if pushed records as a positive force and if pulled records as a negative force. The maximum force is $\pm 50\ N$. (1 N=0.2248 lb.) The force sensor can be calibrated. Later on you will use the **Calibration** button in the **Tools** column to calibrate the force sensor. There is a tare button located on the side of the force sensor which zeros the force sensor out. Also, you can zero out the force sensor with a mass on it. This is a very useful feature that allows you to cancel out a given force and have the sensor give only changes from that force.

Photogate/Smart Pulley A digital sensor that combines a photogate sensor with a pulley that has spokes. As the pulley turns the photogate is successively blocked by the spokes. The smart pulley can be programmed to display position, linear speed, linear acceleration, etc.

Picket Fence A sheet of clear plastic with opaque bands on it. When a picket fence is passed through a photogate the photogate beam is alternately blocked and transmitted. A display can be programmed to give the position, speed, and acceleration of the picket fence. It is necessary to program Capstone for the band distances of the picket fence. This is the distance from the beginning of one opaque band to the beginning of the next opaque band.

1 Purpose

To verify Newton's 2nd law and some applications of this law.

2 Theory

Let $\vec{F}$ be the force in newtons (N), m the mass in kilograms (kg), and $\vec{a}$ the acceleration in $m \cdot s^{-2}$. Newton's 2nd law states that

$$\vec{F} = m\vec{a}.$$

This is a vector equation but in this lab the motions are in one linear dimension and the vector notation can be dropped. This law can be applied to an entire system or to any part of the system. Here we assume that the system is a rigid body and that the forces are applied in such a way that the body does not rotate. The force $\vec{F}$ is the sum of all the forces acting on the chosen body or system. This can also be called the net force or the total force.

Let m be the mass of an object on or near the surface of the earth, M the mass of the earth, R the radius of the earth, and G Newton's gravitational constant. The gravitational force F_G between m and M is given by Newton's gravitational law as

$$F_G = \frac{GmM}{R^2} = mg,$$

where g is called the acceleration due to gravity (on the surface of the earth) and is given by

$$g = \frac{GM}{R^2} = 9.81\ m \cdot s^{-2}.$$

F_G is more popularly known as weight. The above has 2 important applications.

1. The weight of an object in N is equal to the mass in kg times g=9.81 $m \cdot s^{-2}$.
2. If the only force on a dropped object is F_G, then Newton's 2nd law gives $mg = ma$, or $a = g$. Hence the name for g.

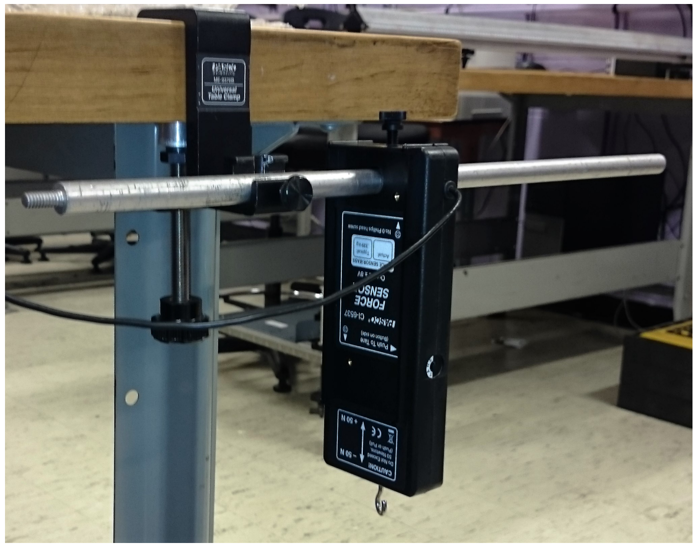
3 Does $F = ma$?

3.1 Description

The force sensor will be used to measure the net force (F) on a mass (m) and the motion sensor will be used to measure the acceleration (a). A mass is hung on the force sensor and the combination of the mass with the force sensor is moved in a vertical direction. The measured acceleration should be equal to F/m if Newton's 2nd law holds.

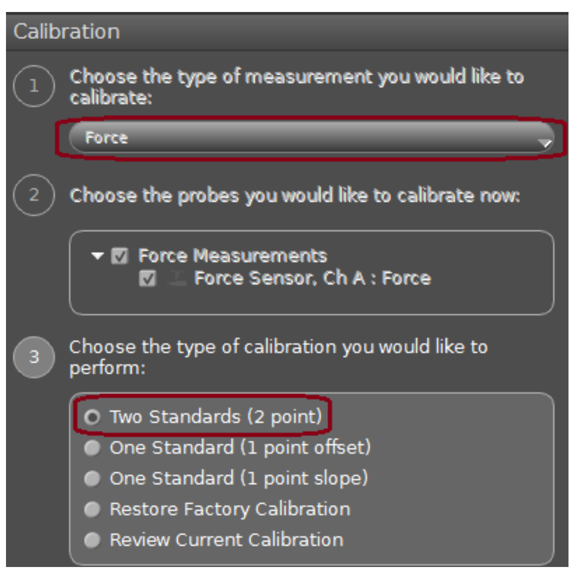
3.2 Programming

Check that the motion sensor and the force sensor are plugged in and note the inputs used. Start Capstone from the desktop and click on **Hardware Setup** located below the **Tools** column. An image of the interface will come up. Program Capstone for the digital motion sensor by clicking on the digital input that the motion sensor is plugged into. A window will pop up, scroll down and click on **Motion Sensor II**. The default speed of sound and sample rate is fine. Repeat for the **Force Sensor**. Next click on the orange tack located on the top right corner of the hardware setup window to reduce overlapping.



3.3 Calibrating the Force Sensor

1. Suspend the force sensor from a horizontal rod. Look at the following image.
2. In Capstone click on the **Record button**. You need to run the program to calibrate the Force Sensor.
3. Hang a 0.5 kg mass on the force sensor's hook.
4. On the side of the force sensor press the tare button to zero out the sensor.
5. In the **Tools** column of Capstone click **Calibration** .
6. Select force and click next.
7. Pick "Two Standards (2 point)" and then next.

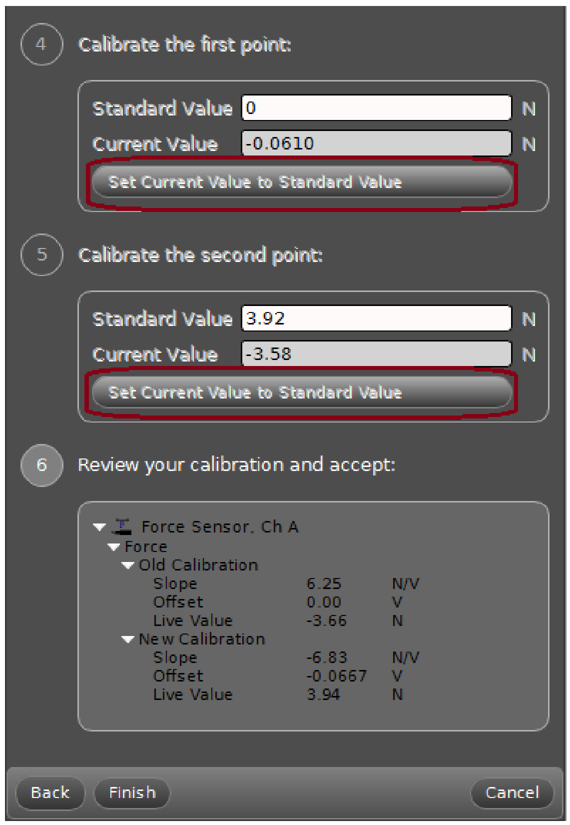


8. The calibration for the first point will come up. Enter 0 in the **Standard Value** box. Click **Set Current Value to Standard Value** in the calibration point 1 box.

9. After calibrating the first point, hang two 0.2 kg masses from the 0.5 kg mass already on the force sensor.

10. You will calibrate the second point by entering the weight of your two 0.2 kg masses in the **Standard Value** box. The weight in newtons will be $0.400 \times 9.81 = 3.92$. Strictly speaking you should enter a negative number. For comparison with the acceleration, it is more convenient to change the sign and enter the weight as a positive quantity. Why should you enter a negative number? Explain.

    Click **Set Current Value to Standard Value** in the calibration point 2 box.



11. Click finish.

12. Click **Stop** in the Capstone program.

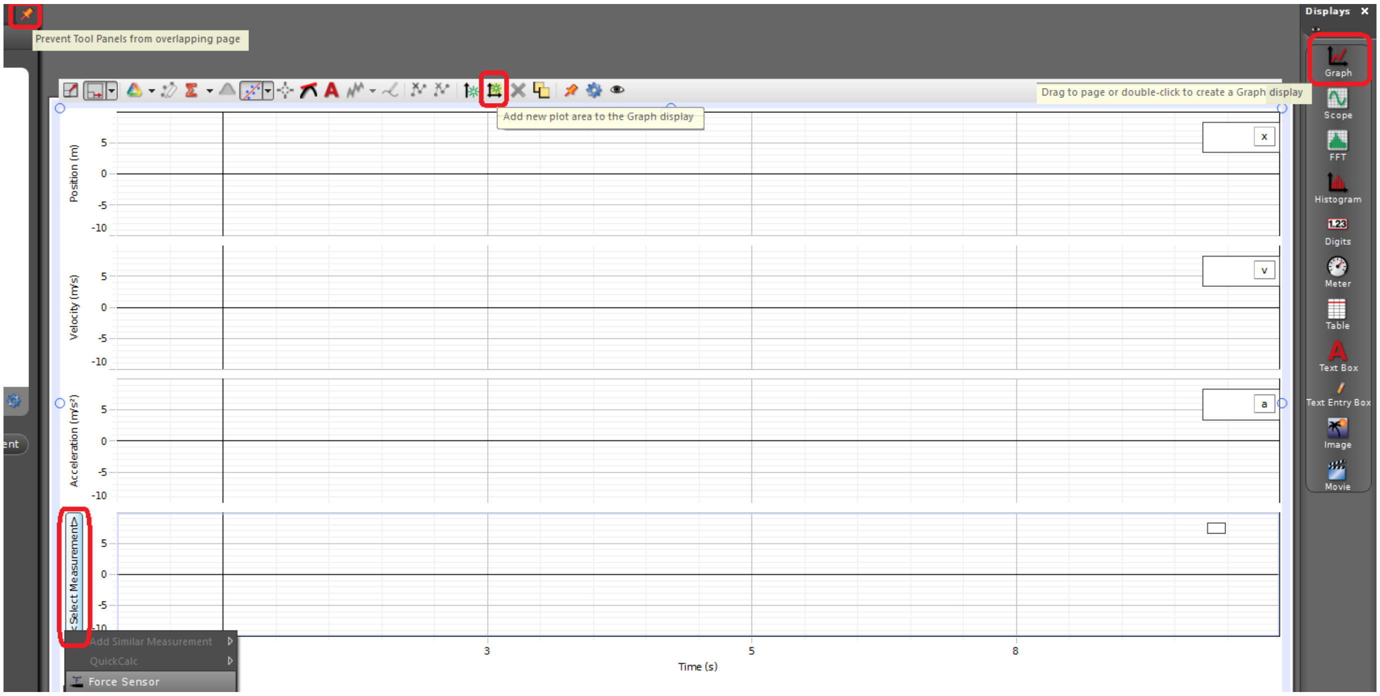
13. Remove the two 0.2 kg masses from the force sensor but leave the 0.5 kg mass.

14. Go to the **Data Summary** in the Tools column and delete the data it recorded.

The force sensor has been calibrated to read zero when the mass (0.5 kg) is at rest. The net force when the mass is accelerated will now be given by the output of the force sensor.

3.4 Graph Setup

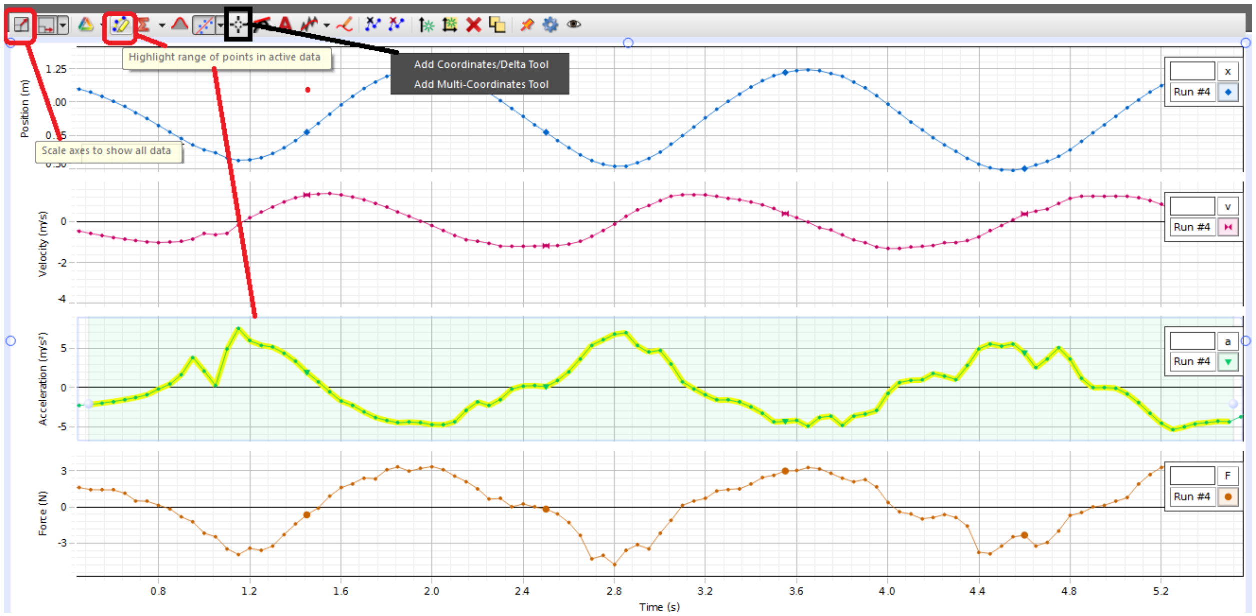
Now you will setup a force, position, velocity, and acceleration graph. Drag the **graph** icon from the **displays** column to the center. On the top center part of the graph click on the **add new plot area to the graph display** icon three times. Configure each graph by clicking on **Select Measurements** and choosing the appropriate label. Each graph will display a separate measurement. Look at the following image for visual assistance.



Don't forget to click on the orange tack located on the top right corner of the hardware setup window to reduce overlapping.

3.5 Taking Data

Place the motion sensor on the floor with the grill pointing up. Be sure that it is far enough away from the edge of the bench so that it does not measure the height of the bench. Tape an index card along the bottom of the hanging mass to aid the reflections back to the motion sensor. Carefully move the force sensor with the 0.5 kg mass attached and hold it over the motion sensor. Have your partner click **Record** and move the force sensor up and down 5 times in a vertical line above the motion sensor. Click **Stop**. Examine your data. You should take several runs to determine how to get the best data. You will probably do better if you move the sensor fairly quickly up and down, but you should not move so quickly that the mass disengages from the sensor, so watch your feet!!! To aid your analysis click on the acceleration curve. Next, click on the **Highlight range of points in active data** icon. Highlight the best region of the acceleration graph, select a minimum of two cycles. Click on the **Scale axes to show all data** icon. Another tool for graph analysis to use is the **Add a coordinate tool** icon and select "Add Multi-Coordinate Tool."



3.6 Analysis

Compare the graph for force with the graph for acceleration. Does the curve for force pretty much duplicate the shape of the curve for acceleration? What is occurring at the zero crossing for velocity, acceleration and force? Explain in detail. If you made the same motion with the force sensor but at a different distance from the motion sensor, which of your 4 graphs would differ from the ones you actually took? Explain.

4 Newton's 2nd Law Applied To A System.

4.1 Description

Newton's laws are tested for a system of 2 masses connected by a string. Mass M_1 is hanging from a vertical string. The string goes over a smart pulley and is attached to a mass M_2 which is a glider attached to a horizontal string and lies on a horizontal air track. The glider on the air track is held stationary and then let go. The motion of the string and hence of the masses is measured by the smart pulley.

4.2 Theory

Let the tension in the string be T and the common acceleration of the masses be a. If the positive directions are taken as down for M_1 and toward the pulley for M_2 the 2nd law applied to each of the masses gives

$$M_1 g - T = M_1 a \text{ and}$$

$$T = M_2 a.$$

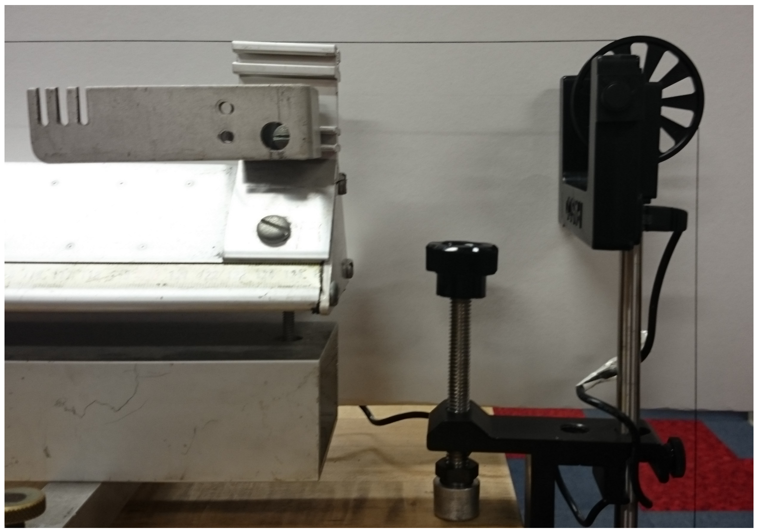
Eliminating T results in

$$a = \frac{M_1 g}{M_1 + M_2}.$$

The above analysis assumes that the pulley is massless and frictionless. If either of these assumptions is not true the tension in the string is not the same on each side of the pulley.

4.3 Set Up and Programming

Remove the rod from the clamp that was used in part one. Position the clamp at the end of the air track with the screw on top of the bench, and insert the photogate/ smart pulley into it. The setup is shown in the image below.

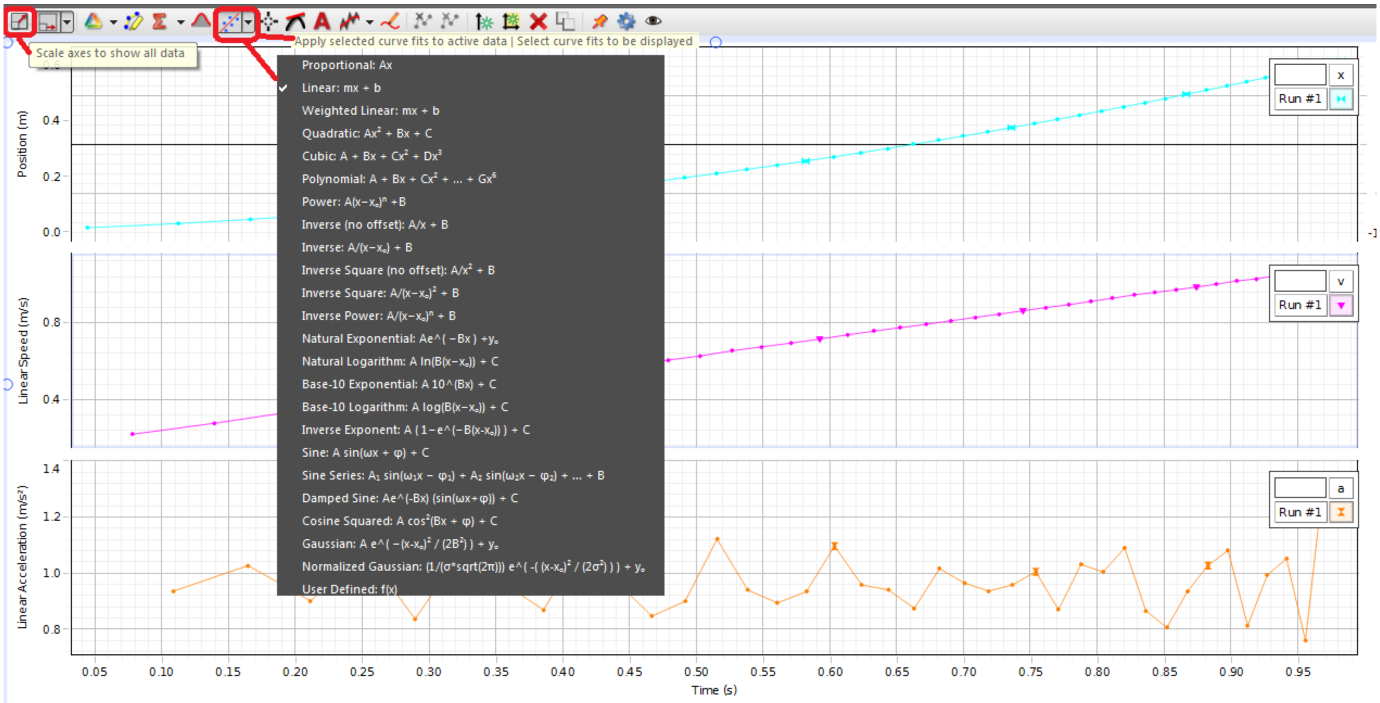


Close and restart the Capstone program. Check that the photogate/ smart pulley is plugged in and note the input. Click on that input in the hardware setup window and program it for **photogate with pulley**. Click on the **Timer Setup** icon in the tools column. The **Pre-Configured Timer** will be selected. Make sure that position, linear speed, and linear acceleration are checked. Also, that the pre-set parameters of Spoke Arc Length is 0.015 m and Spoke Angle is 36 degrees. If everything is okay click on the Hardware Setup icon. If not program for the correct parameters and click save. Next, open the graph display as you did in section 3.2, but this time select position, linear speed, and linear acceleration.

First use the 18.7 cm long glider and level the air track. The leveling adjustment for the air track is located at the opposite end of photogate/smart pulley. The string has two loops. Attach one end of the string to the glider, pass the string over the pulley, and attach a 20 g mass to the other end. Adjust the smart pulley so that the string next to the glider is horizontal and passes through the groove in the end of the air track. Check that when the glider is a few centimeters from the end of the air track the hanging mass is a few centimeters from the floor.

4.4 Data Taking

Turn the airtrack on. Draw the glider back from the end of the track as far as you can without having the mass hit the clamp holding the smart pulley. Let go of the glider and click **Record** at the same time. Click **Stop** just before the glider hits the end of the air track. Click on Linear speed graph. Next, click on the **Scale axes to show all data** icon. Click on **Apply selected curve fits to active data** icon and select Linear. Determine the slope of the linear speed curve. To rescale the graph click on the graph and then **Scale axes to show all data** icon.



You will use a linear curve to determine the slope of the velocity curve. Repeat for masses of 30g and 40g. You will repeat the previous steps using a 28.7 cm long glider with masses of 40, 50, and 60 grams.

4.5 Analysis

Compare your results to the theoretical values. How well do they agree? What are possible reasons for any disagreement? Draw free body diagram of all the forces that both masses are being subjected too when M1 is free falling.

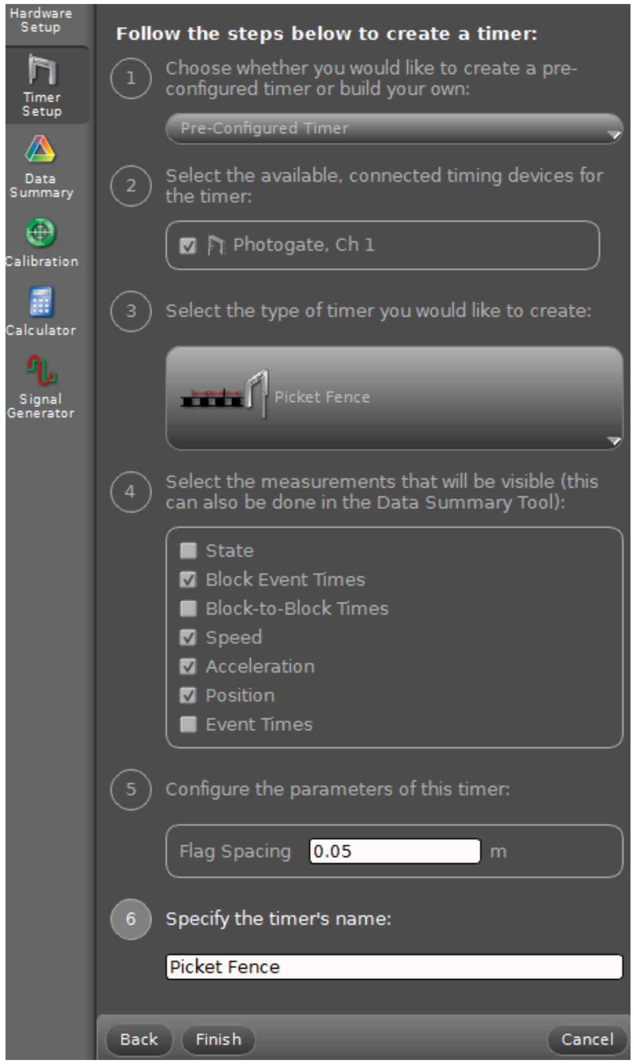
5 The Acceleration of Gravity, g

5.1 Description

A picket fence is dropped through a digital photogate sensor. The acceleration of the picket fence is measured and compared to g.

5.2 Set Up and Programming

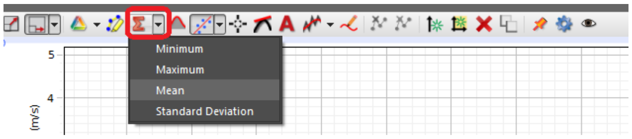
Place the photogate stand near the edge of the bench and have the photogate itself extend over the edge of the bench. Restart the Capstone software. Check if the photogate sensor is plugged in and note the channel. Program Capstone for the digital channel that the photgate is plugged into. A **Timer Setup** icon will come up in the **Tools** column. Click on it. Now configure the photogate sensor for the picket fence. Follow the 6 steps in the illustration on the next page and click **Finish**



The flag spacing is 0.05 m. This is the correct value for the picket fence used in this experiment. Verify this by using the meter stick. Set up the graph display for speed and acceleration.

5.3 Taking Data

Put bubble wrap or a few coats on the floor directly beneath the photogate to act as a cushion for when the picket fence hits the floor. Hold the picket fence just above the photogate, click the **Record** button, and let go of the picket fence. Click **Stop**. (Capstone does not actually take data until the photogate beam is first blocked, so there is no need to drop the picket fence immediately after the Rec button is clicked.) Determine the acceleration of the picket fence. Take a few runs to have some statistics. Keep in mind that you can do a linear fit along the speed graph, or you can take the mean average of the best part of the acceleration graph. Always click upon the graph you want to analyze. To take the mean average value of the acceleration curve click on the acceleration graph. Click on the down arrow next to sigma icon and check Mean. Click on the sigma button and the overall mean average value will come up. Select the best part of the graph with the highlight feature.



5.4 Analysis

Compare your results to g. What contributes to the errors? Explain. What is ocurring with the speed of the picket fence? Explain. If you change the height that you drop the picket fence through the photogate sensor will it effect the acceleration values or speed? Explain.

6 Finishing

Please return the bench to the condition in which you found it, so this means be considerate for your fellow humans. Remove the smart pulley from the bench clamp and use the bench clamp to mount the rod and force sensor. Thank you.