Lab 2: 1-D Motion

Objectives

In this experiment, you will

- Describe motion with constant acceleration,
- Understand the effect that error propagation has on measurement results,
- Discuss the advantages and disadvantages of using mathematical models of physical phenomena.

Apparatus

1. 1-2 m Track, Bumper
2. Wireless Smart Cart
3. Pulley with Clamp
4. Mass Hanger (~15 g)
5. String
6. Laptop
7. Bluetooth Adapter

A demonstration of the apparatus is set up on one of the lab tables for reference.

Setup

Set up the activity according to the directions in the “capstone pdf”.

Warm Up

For this part, do not attach any mass to the cart!

1. Open the position vs. time graph.
2. **Where is the “origin” of the sensor’s coordinate system?** Is it at one end of the track or somewhere in the middle? You and your group should decide where you would like to set the coordinate system’s origin to be used for your measurements. Depending on the equipment, you can “zero” the sensor to set the origin to be where you want.

3. Give the cart a gentle nudge. *Start recording data after giving the cart a soft push* and stop recording data before the cart reaches the end of the track. **Based on the sensor’s data, what is the positive direction of the x-axis relative to the track and the**

sensor? Does this data confirm the location of the origin of the coordinate system?

Let the Phun begin

You are now ready to study the motion of the cart under the influence of a constant force. A constant net force acting on an object will cause that object to move at constant acceleration. This means that the object will change its speed and/or direction of travel at a constant rate. In 1- D motion, this will cause the object to either speed up, slow down, or change direction along a line.
To study 1-D motion, set up the cart such that it is under the influence of a constant net force. You can do this in a number of different ways. In this lab, attach the cart to a mass and a pulley, as directed by the instructor.

1) Record Data. Starting from one end of the track, give the cart a gentle push such that it begins moving opposite to the direction of the constant net force acting on it. Eventually, the cart should reverse direction and return to its starting position. *Record data as soon as the cart starts to move on its own along the track and stop recording before it goes off the end of the track*.

2) Study the position vs. time graph.
    a. **What type of curve do you think best describes the cart's position vs. time graph (linear, quadratic, exponential, etc.)?**

    b. Choose an interval in time to perform a "quadratic fit" approximation to the curve in the position vs. time graph (choose an interval that seems to be "least noisy"). **What is the equation for the quadratic fit that approximates the position curve? Report the uncertainties as well.**

    c. **From the plot, what is the position of the cart at time t = 0? What is the value of C from the quadratic fit? How does C in this model differ from the actual starting position of the cart? From these data, is it reasonable to say that C represents the initial position of the cart? Why or why not?**

d. **If the values of C and the cart's actual starting position differ significantly, can we say that the mathematical model is "wrong"? Why or why not?**

e. To explore the answers to the previous questions, **pick some value for time and plug it into the quadratic fit equation**. Be sure to choose a time value that falls somewhere in the time interval during which recorded the cart's motion. The result of this calculation will be the mathematical model's prediction for the cart's position at that time.

f. **Do a percent difference to compare the equation's predicted result with the measured position of the cart at that time**. **How well does the mathematical model for the cart's position match with the measurement of the cart's actual position? Is it reasonable to use this model to make predictions of the cart's position?**

3) position vs. time and slope

a. **At which point or points is the slope of the tangent line at a point on the curve nearly horizontal? What was the cart doing during at that time (was it speeding up, slowing down, changing direction, stopped, etc.)?**

b. **During which time interval(s) is the slope of the tangent line at any point on the curve negative? What was the cart doing during that time (was it speeding up, slowing down, changing direction, stopped, etc.)? In what direction was the cart traveling during this time?**

4) Study the velocity vs. time graph.

a. **What type of curve do you think best describes the cart's velocity vs. time graph (linear, quadratic, exponential, etc.)?**

b. **Choose an interval in time to perform a "linear fit" approximation to the curve in the velocity vs. time graph (choose an interval that seems to be "least noisy"). What is the equation for the "best fit straight line" (linear fit) that approximates the velocity curve?**

c. **Based on your plot, what is the velocity of the cart at time t = 0? What is the value of b from the linear fit? How similar are these two values? What is their % difference? From these data, is it reasonable to say that b represents the initial velocity of the cart? Explain.**

d. **When does the velocity curve cross the time axis? Let's call this value tcross. What was the cart doing at tcross? What was the cart's speed at this time? How does the speed and time at this point compare to what you discovered in part a) of the position vs. time and slope question?**

e. **During which time interval(s) is the velocity negative? What was the cart doing during this interval? How does this interval compare with the interval you found in part b) of the previous question for position vs. time and slope?**

f. **Is the slope of the tangent line at a point on the velocity curve positive, negative, or nearly zero?**

g. **In which direction was the cart moving immediately before tcross? In which direction was the cart moving immediately after tcross?**

5) Study the acceleration vs. time graph.

a. **Choose an interval of time in which to calculate the mean (average) acceleration. Is the mean acceleration positive, negative, or zero during this interval? How does the value for the mean acceleration compare with the value for the slope of the best fit straight line (from the linear approximation) that you obtained from part b) of the previous section? Compare by calculating the percent difference between these values.**

6) Comparing graphs

a. **Carefully compare the "noisiness" of each of the previous graphs (position vs. time, velocity vs. time, and acceleration vs. time). Note: I define "noisiness" to be the amount that a set of points fluctuates from the best fitting curve that models the data. Which graph appears "noisiest"? Qualitatively rank the "noisiness" of each graph, from least noisy to most noisy.**

b. **What do you think the source of the noisiness is in each of the graphs and how do you think error propagation influences it?** Hint: Even though the sensor measures the instantaneous position of the cart, it can only approximate instantaneous velocity and instantaneous acceleration by measuring the average velocity and the average acceleration of the cart over a short time interval. In light of this, think about how the uncertainty in position influences average velocity and how the uncertainty in average velocity influences average acceleration.

c. **What connection(s) do you see between the position vs. time and velocity vs. time graphs? What connection(s) do you see between the velocity vs. time and acceleration vs. time graphs?**

d. **How does the value B from the quadratic fit in the position vs. time graph compare with the velocity intercept b from the linear fit in the velocity vs. time graph? Is it reasonable to say that B = v0x?**

e. **How does the value 2A from the quadratic fit in the position vs. time graph compare with the slope m from the linear fit in the velocity vs. time graph? How does 2A compare with the mean acceleration in the acceleration vs. time graph? Is it reasonable to say that A = ½a?**

f. **Based on your two previous answers, rewrite the quadratic equation obtained from the position vs. time graph in terms of the quantities x, x0, v0x, ax, and t, and rewrite the linear fit equation obtained from the velocity vs. time graph in terms of vx, v0x, ax, and t only.**

Putting it All Together

1. **How did error propagation influence the reliability of the velocity vs. time and acceleration vs. time graphs?**

2. **If you could pick only one graph from which to get all your data (position vs. time, velocity vs. time, or acceleration vs. time), which graph would you choose and why?**

3. **If you look carefully at the position vs. time graph, you may notice that the "parabola" is not quite symmetric and may be skewed in one direction. If you look at the velocity vs. time graph, you may notice that the velocity curve is not quite linear, but has a "kink" in it such that the slope of the velocity line may change at**

the location of the kink. If you look at the acceleration vs. time graph, you may notice that the acceleration distinctly changes from one value to another value. If this is the case with your data, why do you think your graphs look the way they do? Is there something that can account for the way the graphs look that wasn't considered in the mathematical models for the position, velocity, and acceleration?

4. **What are some advantages, disadvantages, and limitations of using mathematical models to describe physical phenomena?**

Motion Along a Line

Apparatus

1. 1 - 2 m Track, Bumper
2. Wireless Smart Cart
3. Pulley with Clamp
4. Mass Hanger (~15 g)
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6. Laptop
7. Bluetooth Adapter

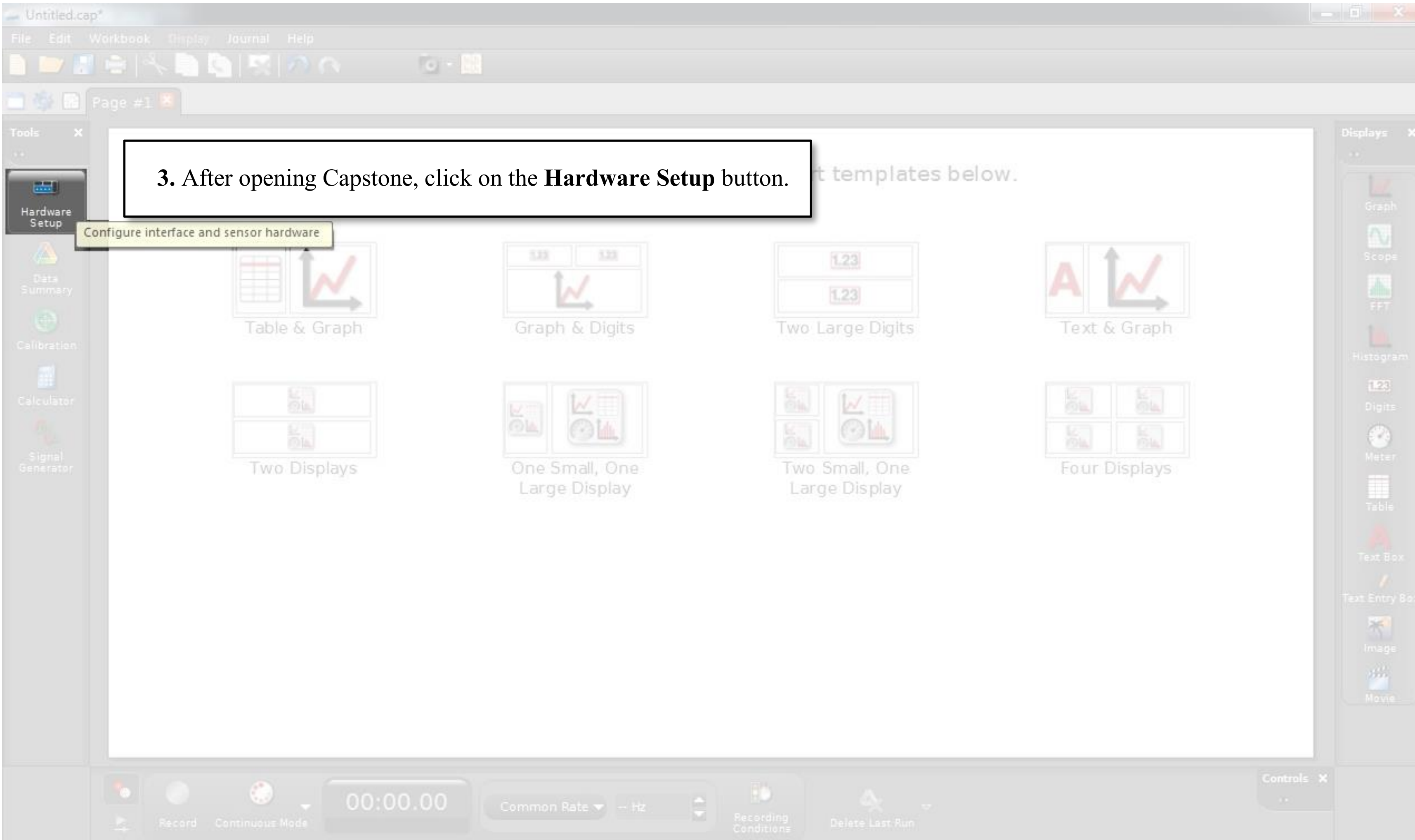
A demonstration of the apparatus is set up on one of the lab tables for reference.

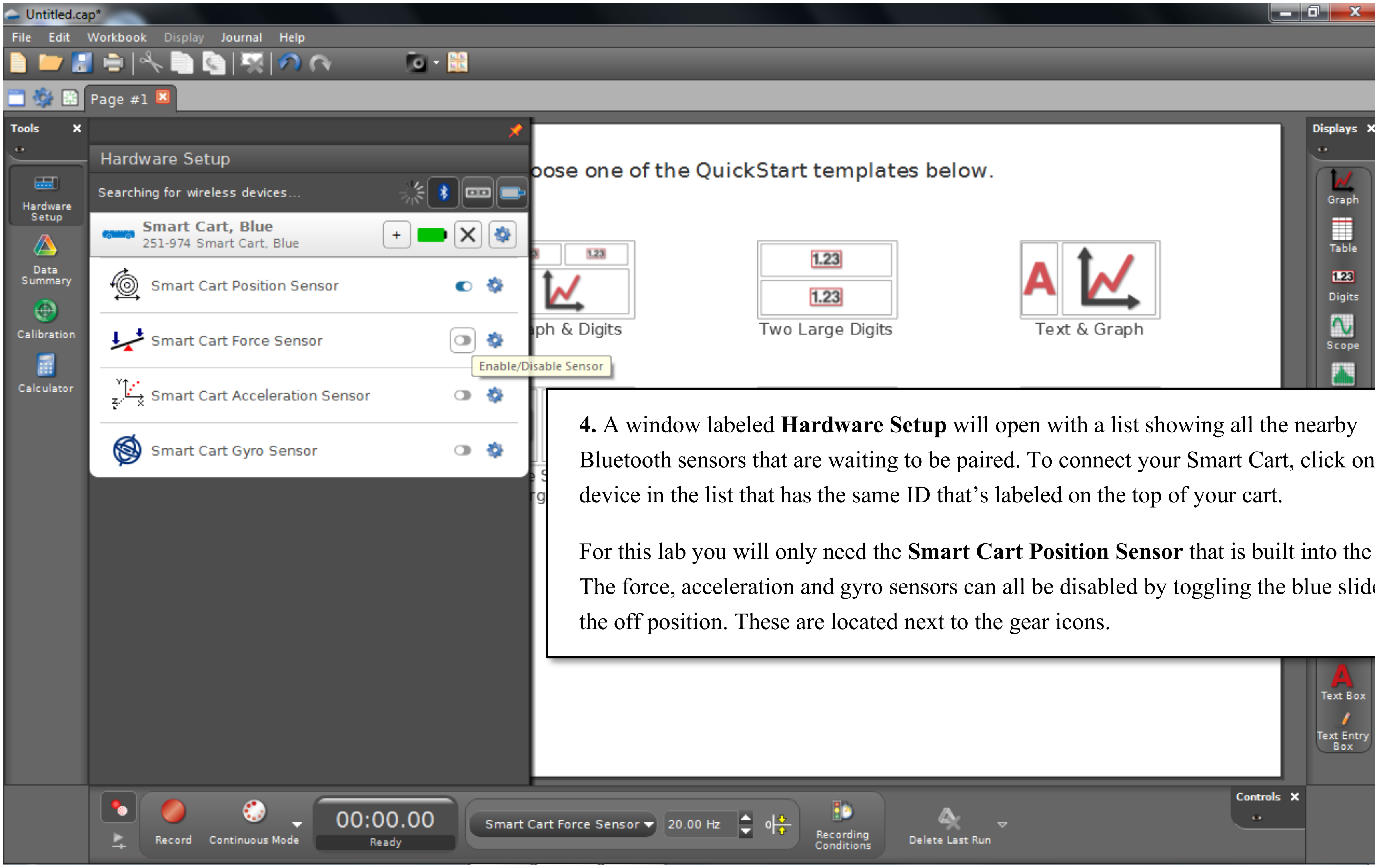
Procedure

1. Make sure a Bluetooth adapter is plugged into one of the USB ports on the laptop that you are using. These are small dongles that have a piece of red tape attached to them. Boot the laptop up in Windows and open up the Capstone software. A shortcut should be located on the desktop. If the software comes up with a window prompting you to install an update, click on the **Remind Me Later** button.

2. Press the power button, located on the side of the Smart Cart that you are using, to turn it on. The LED next to the Bluetooth symbol will start flashing red to indicate that it is ready to be paired with the Capstone software.

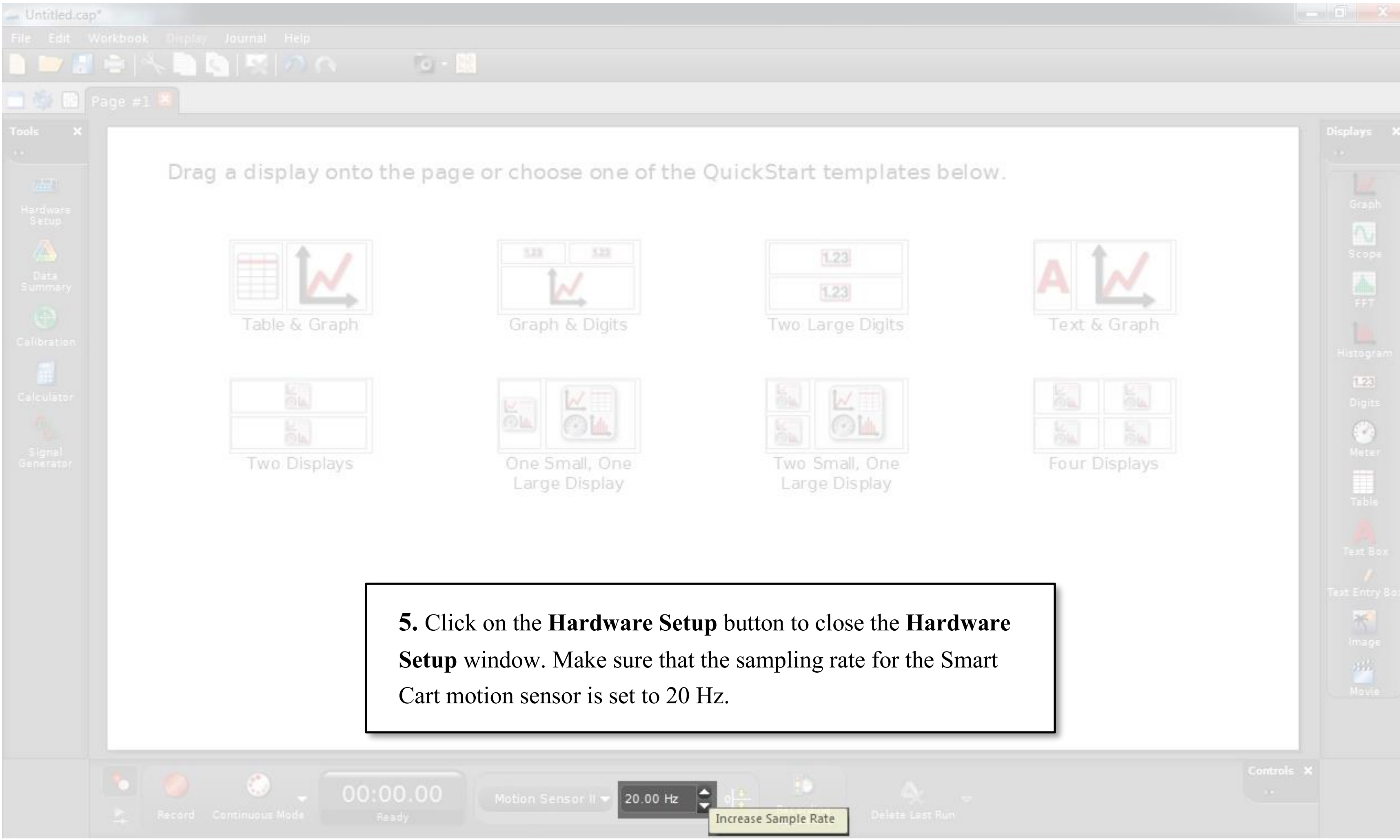
3. After opening Capstone, click on the **Hardware Setup** button.



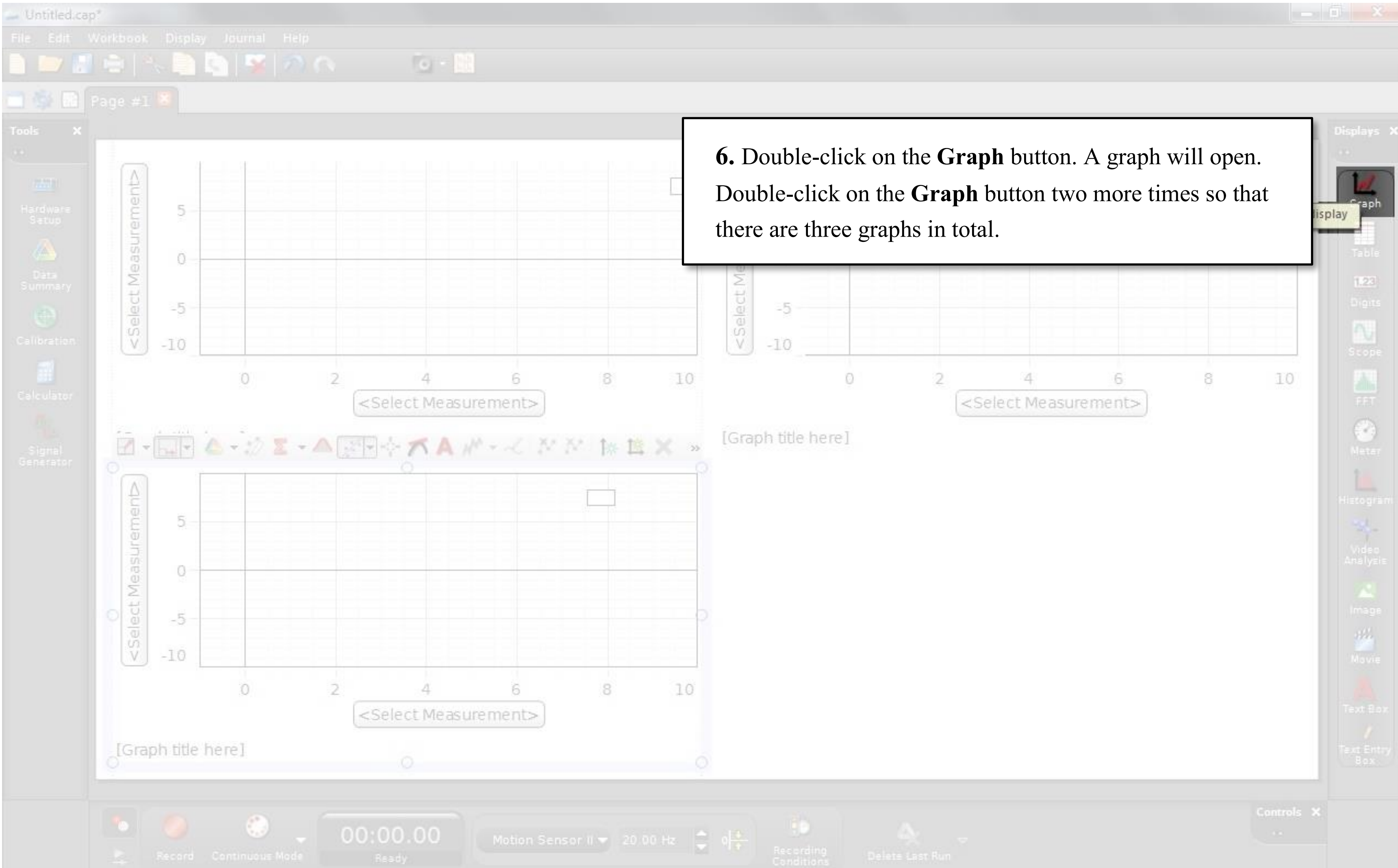


4. A window labeled **Hardware Setup** will open with a list showing all the nearby Bluetooth sensors that are waiting to be paired. To connect your Smart Cart, click on the device in the list that has the same ID that's labeled on the top of your cart.

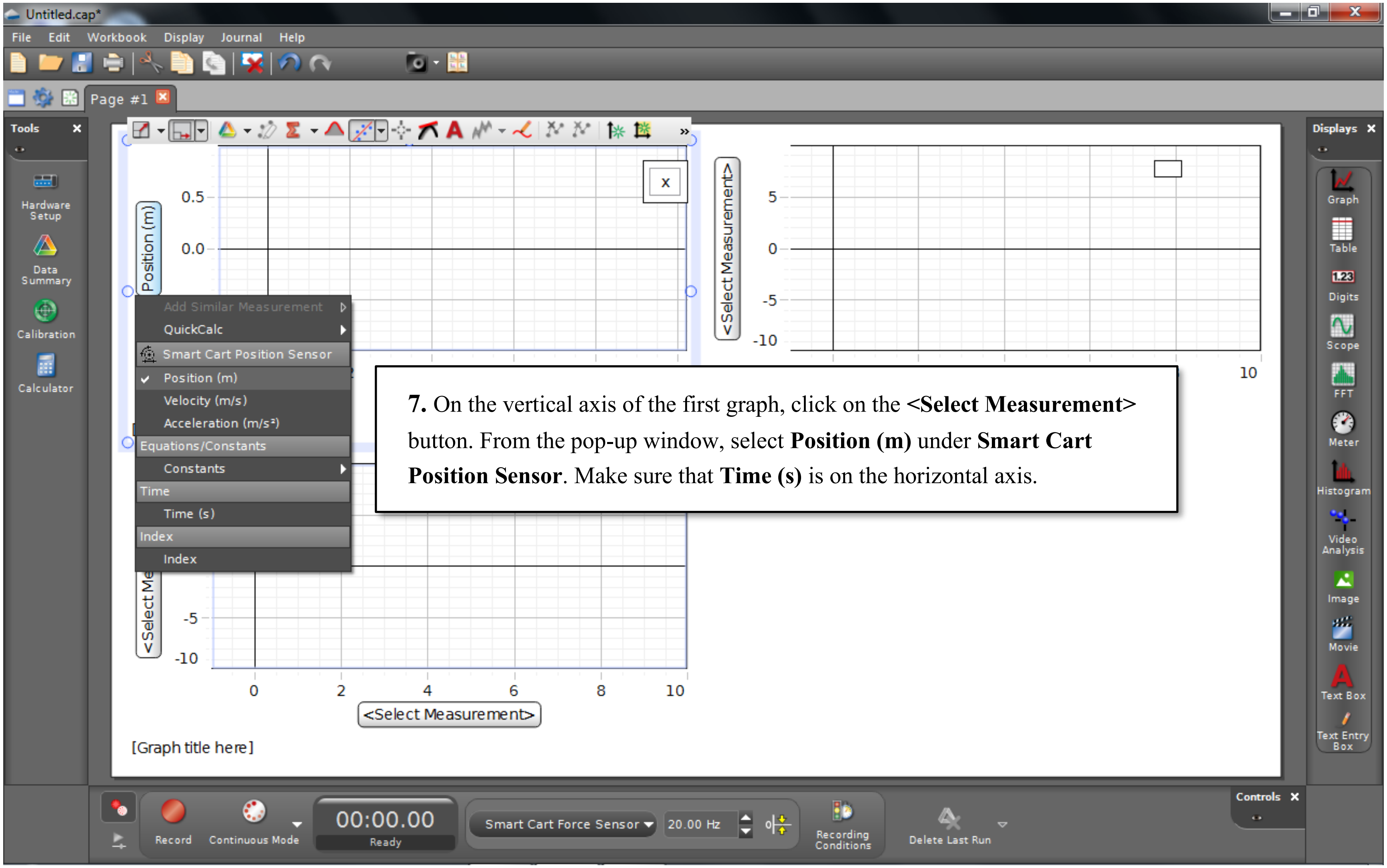
For this lab you will only need the **Smart Cart Position Sensor** that is built into the cart. The force, acceleration and gyro sensors can all be disabled by toggling the blue sliders to the off position. These are located next to the gear icons.



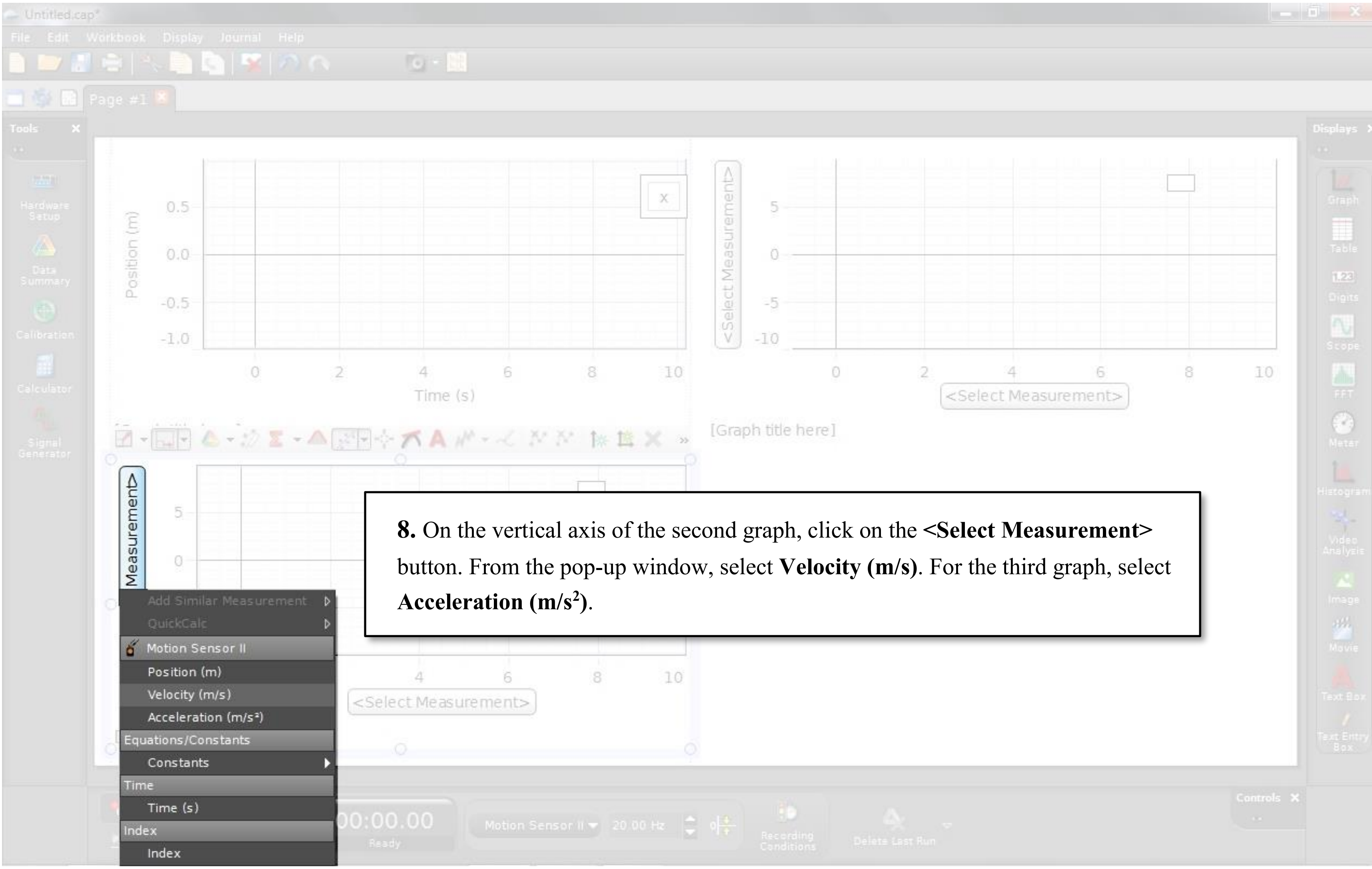
5. Click on the **Hardware Setup** button to close the **Hardware Setup** window. Make sure that the sampling rate for the Smart Cart motion sensor is set to 20 Hz.



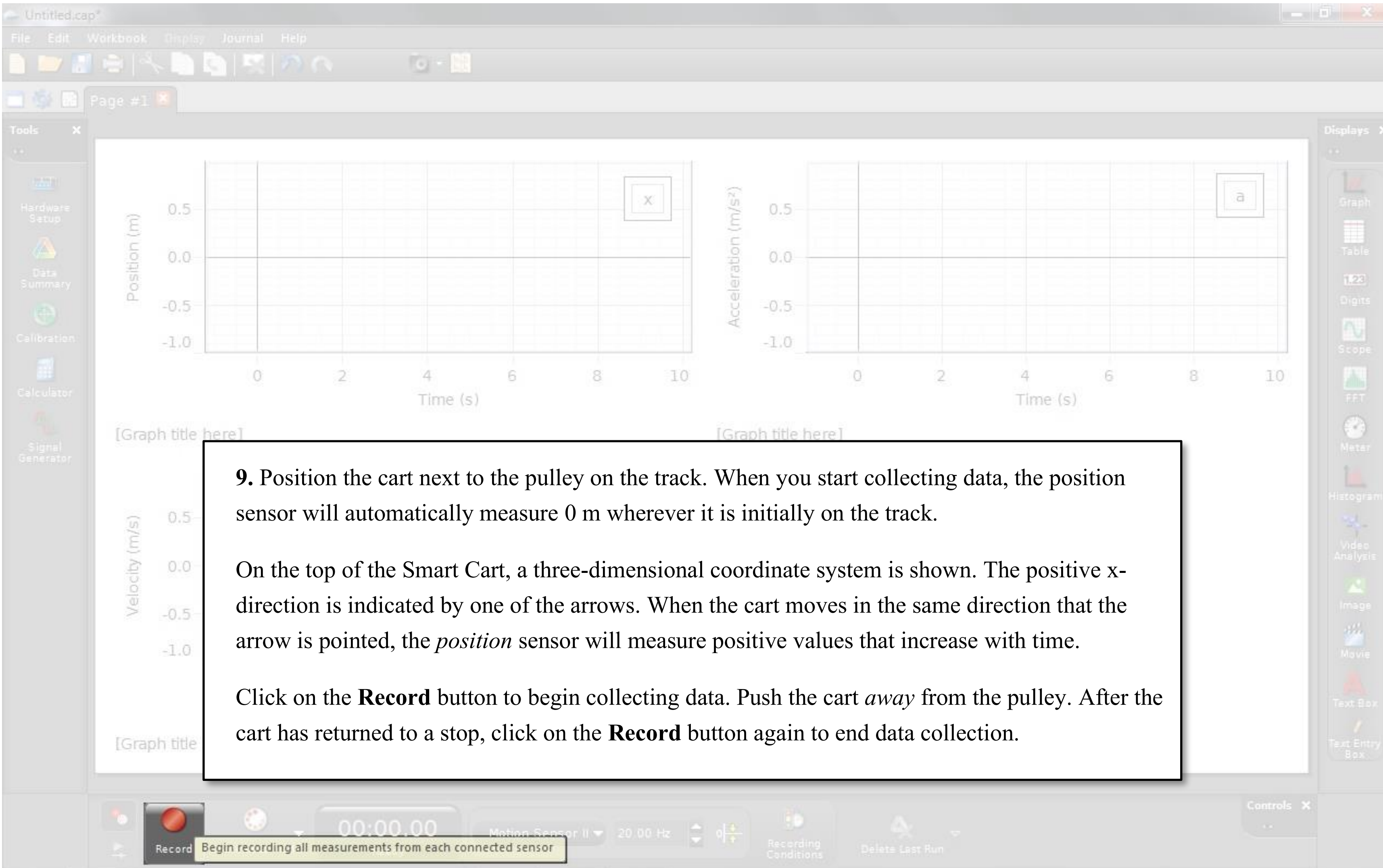
6. Double-click on the **Graph** button. A graph will open. Double-click on the **Graph** button two more times so that there are three graphs in total.



7. On the vertical axis of the first graph, click on the **<Select Measurement>** button. From the pop-up window, select **Position (m)** under **Smart Cart Position Sensor**. Make sure that **Time (s)** is on the horizontal axis.



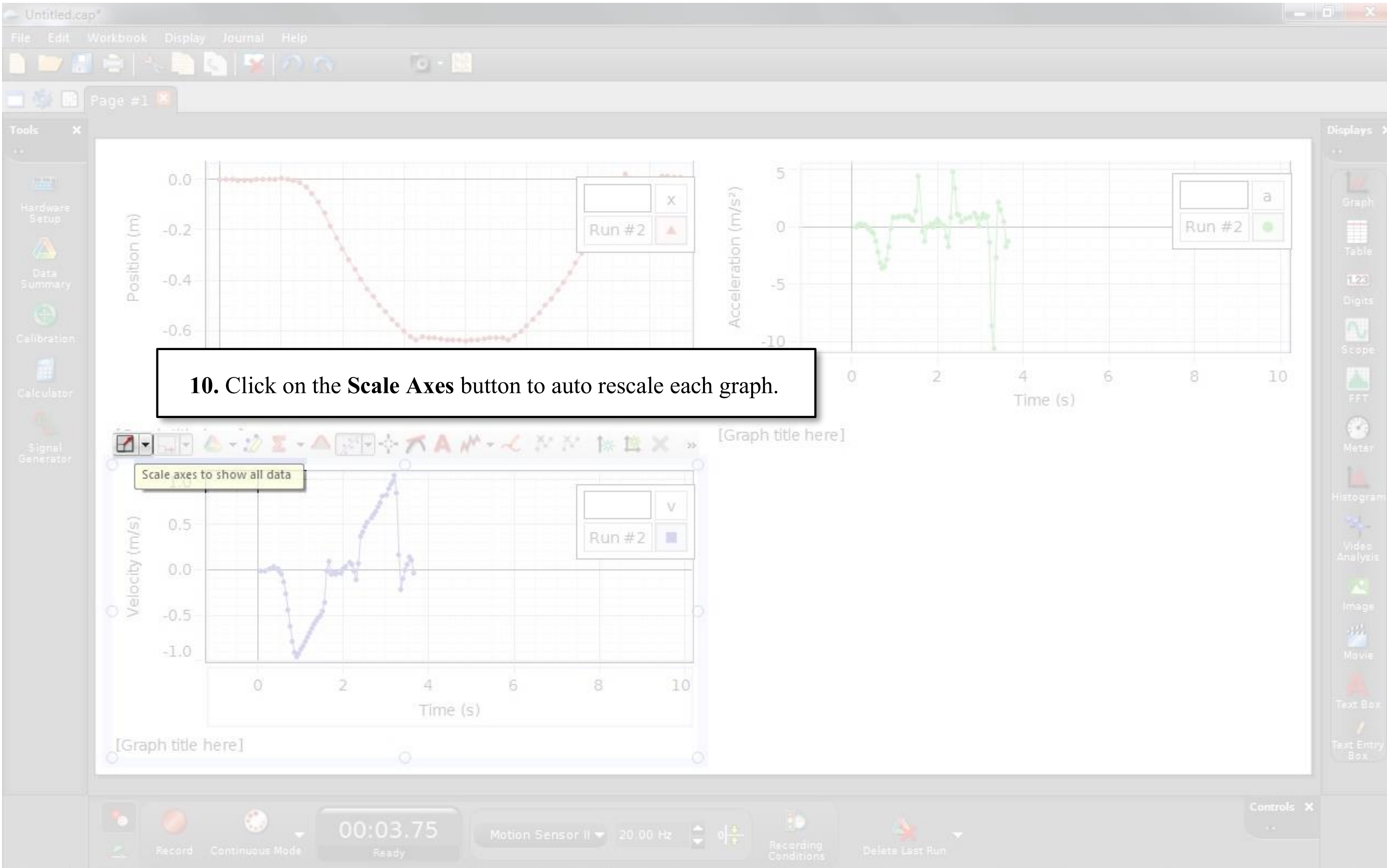
8. On the vertical axis of the second graph, click on the **<Select Measurement>** button. From the pop-up window, select **Velocity (m/s)**. For the third graph, select **Acceleration (m/s^2)**.



9. Position the cart next to the pulley on the track. When you start collecting data, the position sensor will automatically measure 0 m wherever it is initially on the track.

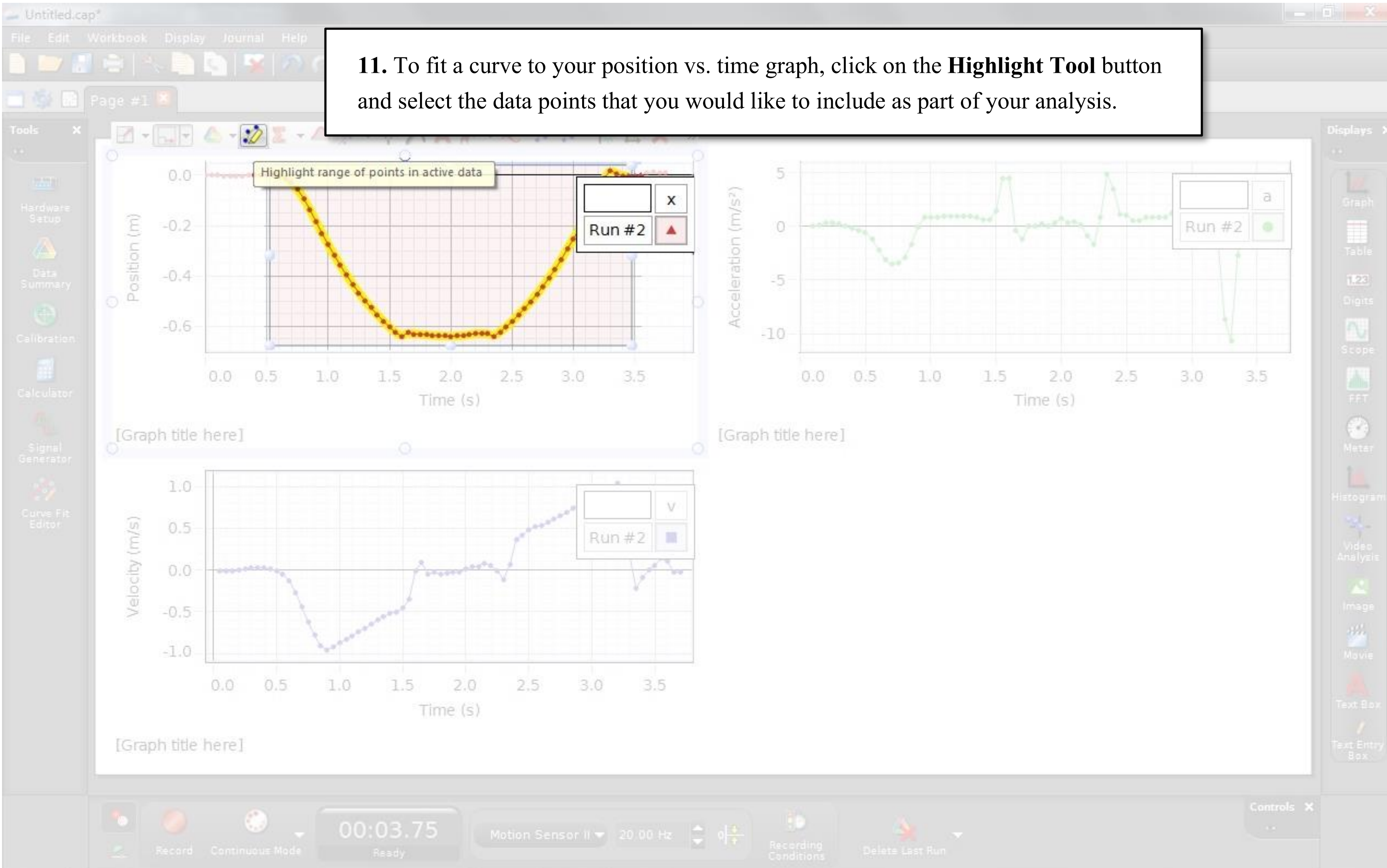
On the top of the Smart Cart, a three-dimensional coordinate system is shown. The positive x-direction is indicated by one of the arrows. When the cart moves in the same direction that the arrow is pointed, the *position* sensor will measure positive values that increase with time.

Click on the **Record** button to begin collecting data. Push the cart *away* from the pulley. After the cart has returned to a stop, click on the **Record** button again to end data collection.

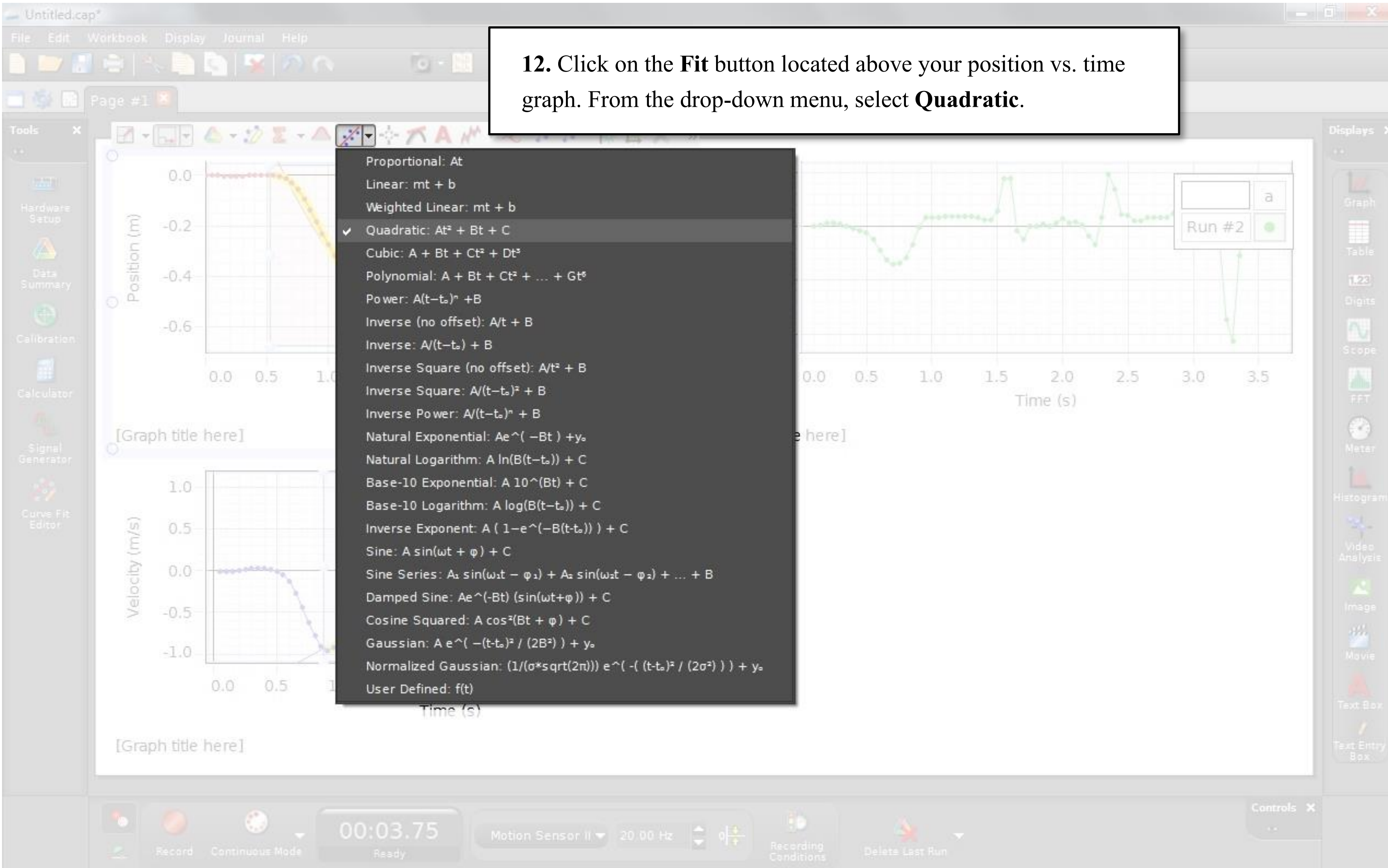


10. Click on the **Scale Axes** button to auto rescale each graph.

11. To fit a curve to your position vs. time graph, click on the **Highlight Tool** button and select the data points that you would like to include as part of your analysis.



12. Click on the **Fit** button located above your position vs. time graph. From the drop-down menu, select **Quadratic**.

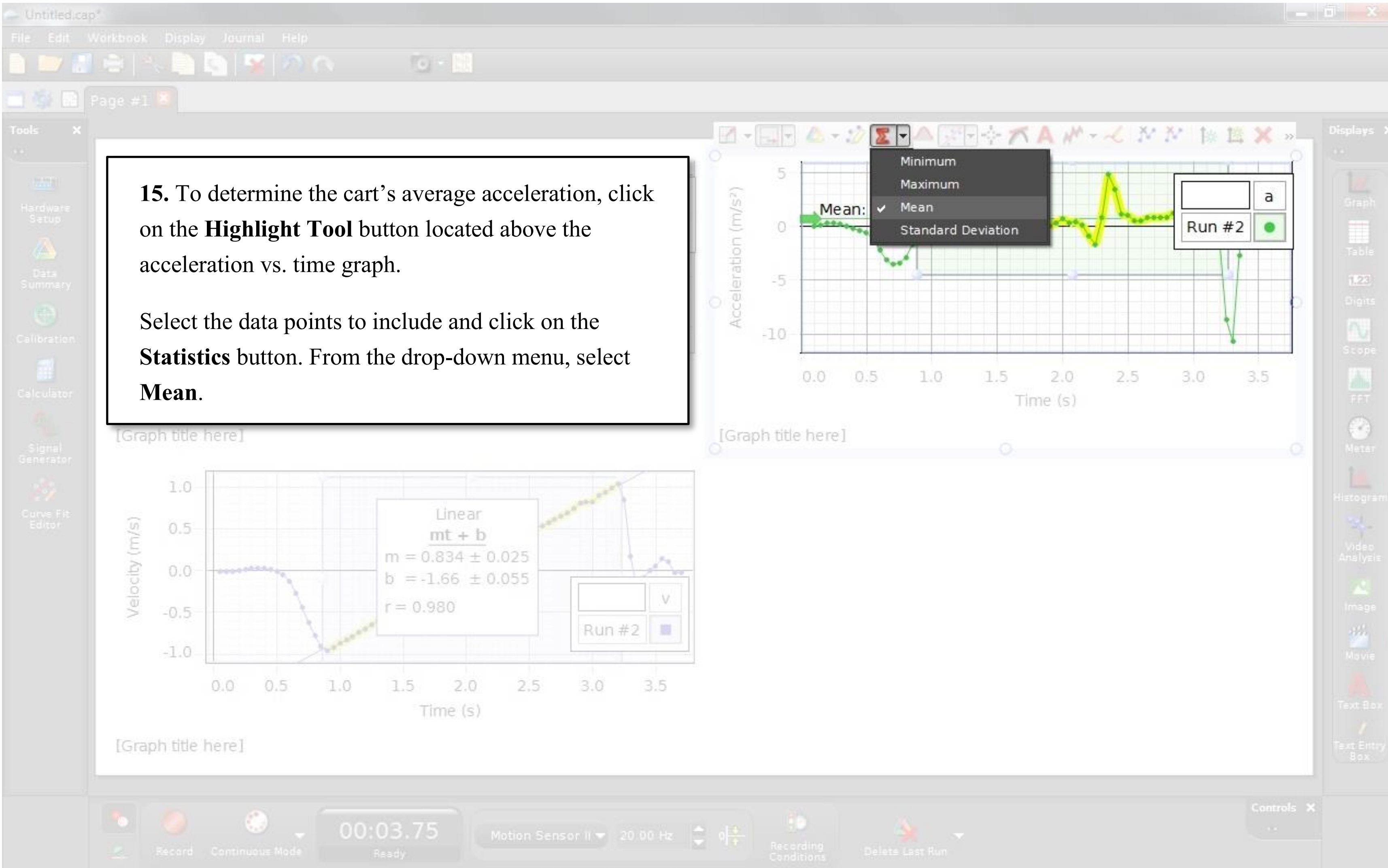


13. To fit a curve to the velocity vs. time graph, click on the **Highlight Tool** button and select the data points for analysis.

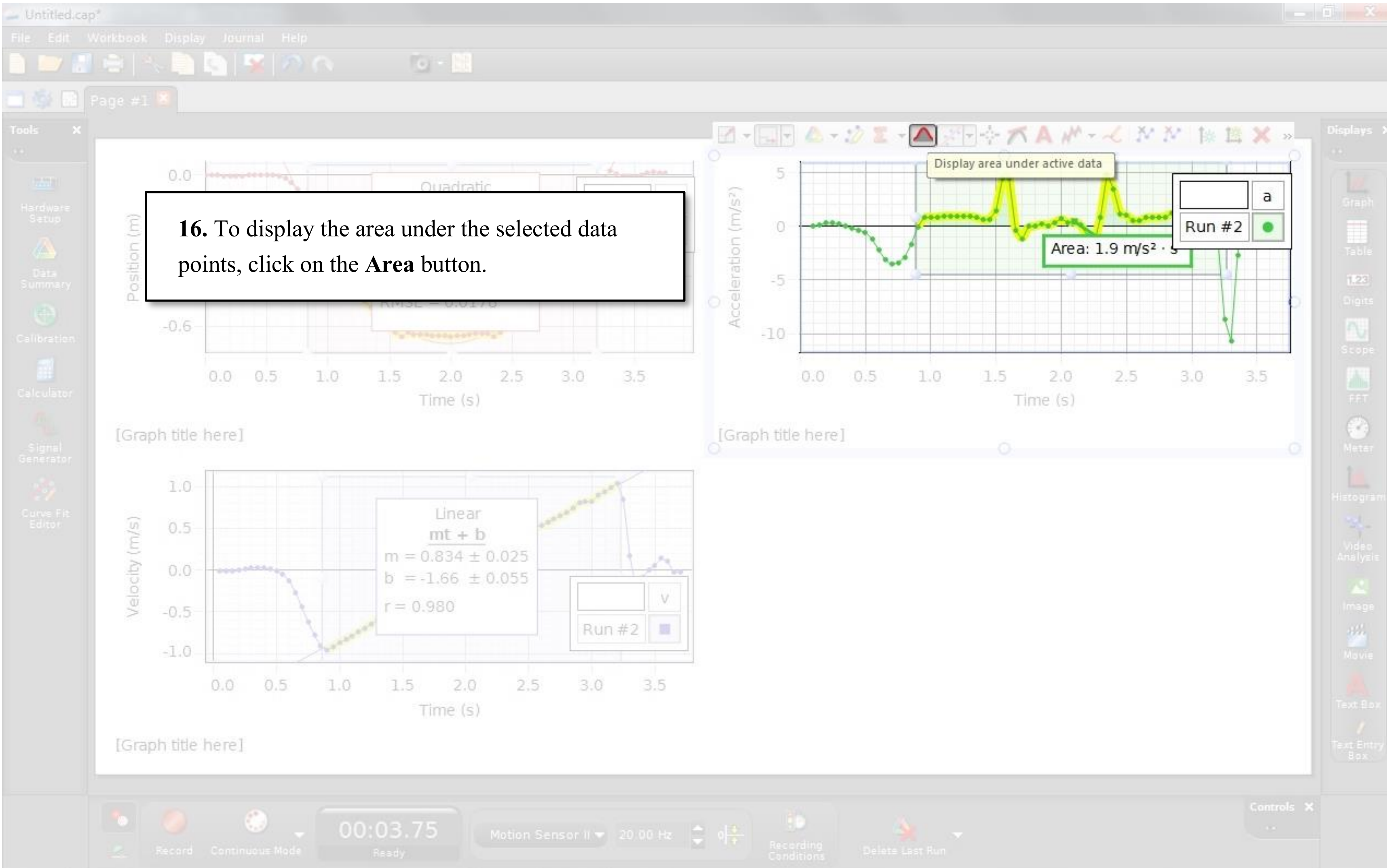
14. Click on the **Fit** button. From the drop-down menu select **Linear**.

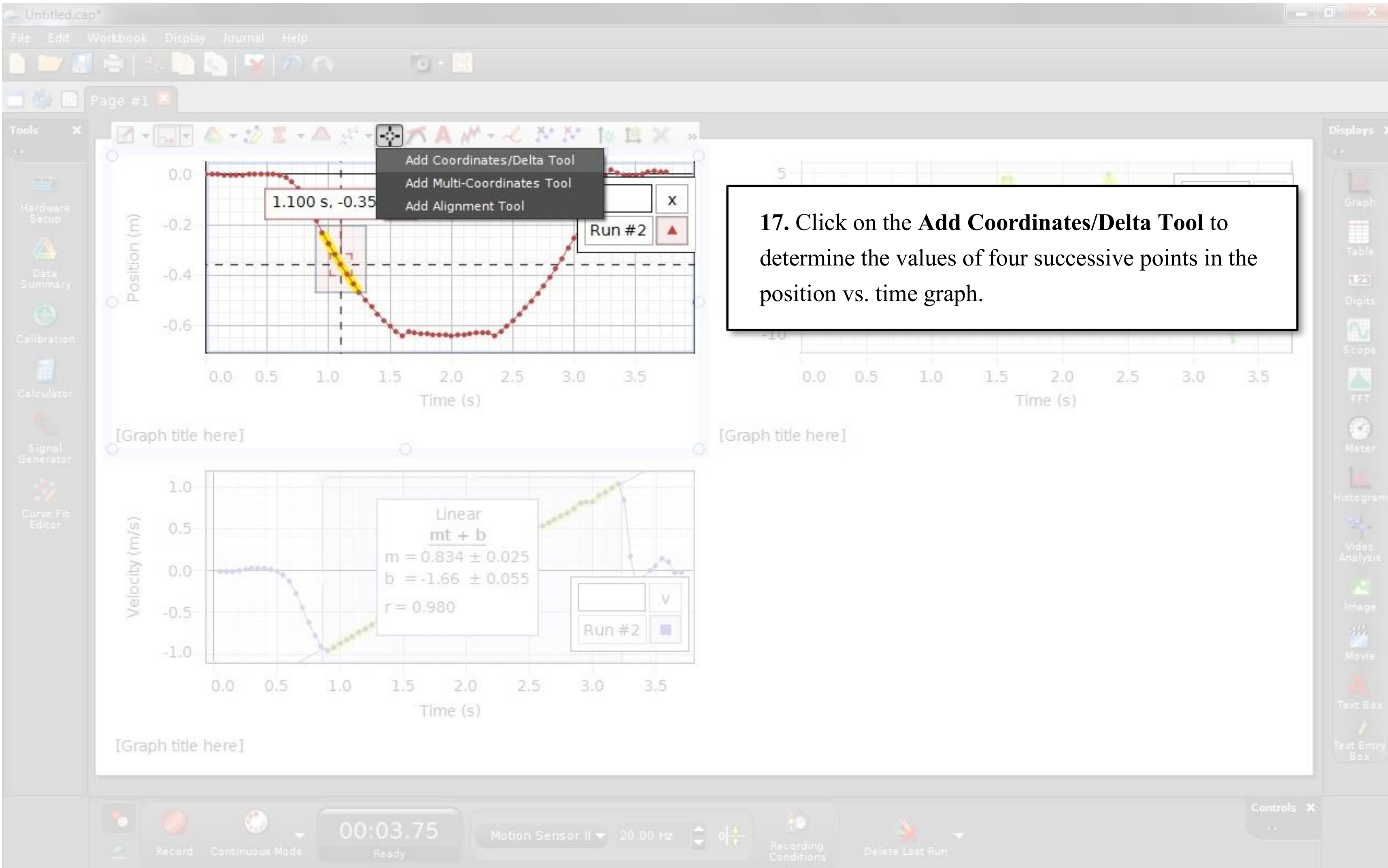
15. To determine the cart’s average acceleration, click on the **Highlight Tool** button located above the acceleration vs. time graph.

Select the data points to include and click on the **Statistics** button. From the drop-down menu, select **Mean**.



16. To display the area under the selected data points, click on the **Area** button.





17. Click on the **Add Coordinates/Delta Tool** to determine the values of four successive points in the position vs. time graph.