NSTA 2025
Philadelphia, PA

Introduction to Vernier: Sensor Basics for Beginners

Experiments

Introduction to Data Collection

- Go Direct® Temperature Probe

Boyle's Law: Pressure-Volume Relationship in Gases

- Go Direct Gas Pressure Sensor

Graph Matching

- Go Direct Motion Detector

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Introduction to Data Collection

Data collection is a very important part of science. Meteorologists collect weather data over time to keep an historical record and to help make forecasts. Oceanographers collect data on the salinity (saltiness) of seawater to study changing trends in our Earth's oceans. While data have been collected by hand for thousands of years, the technology to collect data electronically was developed in the 1950s. Only since the 1980s has this technology been available and accessible to schools.

This experiment was designed to introduce you to two of the most common modes of data collection that will be used in this class. Part I will guide you through collecting and analyzing data over time. A temperature probe will be used to record the temperature of water for 60 seconds at a rate of one sample per second. In Part II, you will collect data using a mode called Events with Entry. This style of data collection allows you to collect one point of data, and then enter in a corresponding value. In this part, the data collected will be the temperature of your hand and the value you enter will be your assigned group member number.

OBJECTIVES

- Become familiar with Graphical Analysis data-collection app.
- Use Graphical Analysis and a temperature probe to make measurements.
- Analyze a graph of the data.
- Use this graph to make conclusions about the experiment.
- Determine the response time of a temperature probe.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis app
Go Direct Temperature
two 250 mL beakers
cold tap water
hot tap water
ice
paper towels

Figure 1

PROCEDURE

Part I Time Graph

1. Place about 100 mL of tap water into a 250 mL beaker. Add two or three ice cubes.

2. Launch Graphical Analysis. Connect the Go Direct Temperature Probe to your Chromebook, computer, or mobile device.

3. Set up the data-collection mode.

   a. Click or tap Mode to open Data Collection Settings.

   b. Change Rate to 0.5 samples/s and End Collection to 60 s. Click or tap Done.

4. Place the temperature probe into the cold water and stir briefly. Then position the probe in the cold-water beaker as shown in Figure 1. **Note**: Make sure the beaker will not tip over from the weight of the probe.

5. Place about 150 mL of hot water into a second 250 mL beaker.

6. When everything is ready, click or tap Collect to start data collection. Do not stir or move the water.

7. When exactly 10 seconds have gone by, quickly move the probe to the beaker containing hot water and allow data collection to continue. Do not stir the water or move the probe during the remainder of the data collection period.

8. Data collection will stop automatically after 60 seconds.

9. Remove the probe from the beaker and dry it with a paper towel.

10. Determine the elapsed time when the highest temperature was reached.

    a. When data collection is complete, a graph of temperature *vs*. time is displayed. Click or tap the graph to examine the data. **Note**: You can also adjust the Examine line by dragging the line.

    b. Find the highest temperature.

    c. Record this temperature (round to the nearest 0.1°C) and the time when it was first reached in the data table.

11. Sketch or export an image of your graph according to your teacher's instructions.

12. You can confirm the time when the highest temperature was reached by viewing the data table.

    a. Click or tap View, , and turn on the Data Table.

    b. Find the time when the highest temperature was first reached. Did you get the same time both ways?

Part II Events with Entry

13. Click or tap File, 🗋, and choose New Experiment. Click or tap Sensor Data Collection.

14. Set up the data-collection mode.

    a. Click or tap Mode to open Data Collection Settings. Change Mode to Event Based.

    b. Enter **Member** as the Event Name and leave the Units field blank. Click or tap Done.

15. Assign numbers to the members of your group by age with the oldest being number one. Record the names in the data table for Part II. Add more lines if needed.

16. Click or tap Collect to start data collection.

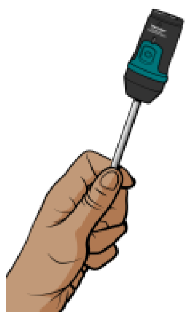


Figure 2

17. Measure the hand temperature of the first group member.

    a. Group member number one should pick up the probe and hold its tip in the palm of his or her hand as shown in Figure 2.

    b. Watch the live temperature readout. When the temperature stops rising, click or tap Keep.

    c. You will be prompted to enter a number. Enter **1** as the student's group member number, then click or tap Keep Point. The temperature and group member number have been saved.

18. Cool the probe down by placing it in the cold water from Part I. Monitor the temperature on the screen and remove it from the water when the temperature reaches 25°C.

19. Pass the probe to the next group member.

20. Repeat Steps 17–19 until every group member has his or her hand temperature recorded, entering the correct group member number for each person.

21. Click or tap Stop to stop data collection.

22. Determine each person's hand temperature by using one of the methods described in Steps 10 and 12. Record the values in the data table.

23. Sketch or export an image of your graph according to your teacher's instructions.

DATA

Part I Time Graph

Maximum temperature (°C)	Elapsed time (s)

Part II Events with Entry

Group member number	Group member name	Maximum temperature (°C)
1		
2		
3		
4		
5		
6		
Group average		

PROCESSING THE DATA

Part I Time Graph

1. Describe the appearance of your graph from Part I.
2. Why is time plotted on the horizontal axis in this experiment?
3. Why is temperature plotted on the vertical axis?
4. Determine the temperature probe's response time. To do this, use your data to find how long it took for the temperature probe to reach the maximum temperature after moving it from the cold water to the hot water.
5. Explain how you determined your answer to Question 4.

Part II Events with Entry

6. Calculate your group's average for the maximum temperatures. Record the result in the data table.
7. Who had the hottest hand?
8. Who had the coldest hand?

Boyle's Law: Pressure-Volume Relationship in Gases

The primary objective of this experiment is to determine the relationship between the pressure and volume of a confined gas. The gas we use will be air, and it will be confined in a syringe connected to a gas pressure sensor (see Figure 1). When the volume of the syringe is changed by moving the piston, a change occurs in the pressure exerted by the confined gas. This pressure change will be monitored using a gas pressure sensor. It is assumed that temperature will be constant throughout the experiment. Pressure and volume data pairs will be collected during this experiment and then analyzed. From the data and graph, you should be able to determine what kind of mathematical relationship exists between the pressure and volume of the confined gas. Historically, this relationship was first established by Robert Boyle in 1662 and has since been known as Boyle's law.

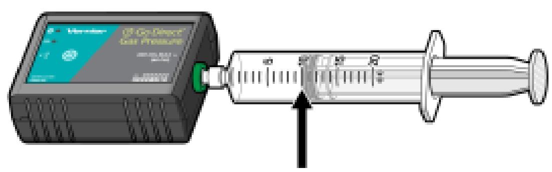


Figure 1

OBJECTIVES

- Use a gas pressure sensor and a gas syringe to measure the pressure of an air sample at several different volumes.
- Determine the relationship between pressure and volume of the gas.
- Describe the relationship between gas pressure and volume in a mathematical equation.
- Use the results to predict the pressure at other volumes.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis app
Go Direct Gas Pressure
20 mL gas syringe

PROCEDURE

1. Prepare the data-collection equipment and an air sample for data collection.

   a. Launch Graphical Analysis. Connect the Gas Pressure Sensor to your Chromebook, computer, or mobile device.

   b. With the 20 mL syringe disconnected from the Gas Pressure Sensor, move the piston of the syringe until the front edge of the inside black ring (indicated by the arrow in Figure 1) is positioned at the 10.0 mL mark.
   c. Attach the 20 mL syringe to the valve of the Gas Pressure Sensor.

2. Set up the data-collection mode.

   a. Click or tap Mode to open Data Collection Settings. Change Mode to Event Based.
   b. Enter **Volume** as the Event Name and **mL** as the Units. Click or tap Done.

3. To obtain the best data possible, you will need to correct the volume readings from the syringe. Look at the syringe; its scale reports its own internal volume. However, that volume is not the total volume of trapped air in your system since there is a little bit of space inside the pressure sensor.

   To account for the extra volume in the system, you will need to add 0.8 mL to your syringe readings. For example, with a 5.0 mL syringe volume, the total volume would be 5.8 mL. It is this total volume that you will need for the analysis.

4. You are now ready to collect pressure and volume data. It is easiest if one person takes care of the gas syringe and another enters volumes.

   a. Click or tap Collect to start data collection.
   b. Move the piston so the front edge of the inside black ring (see Figure 2) is positioned at the 5.0 mL line on the syringe. Hold the piston firmly in this position until the pressure value displayed on the screen stabilizes.
   c. Click or tap Keep and enter **5.8**, the gas volume (in mL). Remember, you are adding 0.8 mL to the volume of the syringe for the total volume. Click or tap Keep Point to store this pressure-volume data pair.

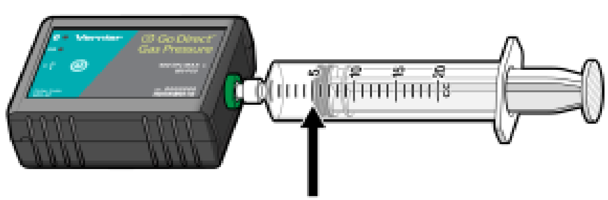


Figure 2

   d. Continue this procedure using syringe volumes of 10.0, 12.5, 15.0, 17.5, and 20.0 mL.
   e. Click or tap Stop to stop data collection.

5. When data collection is complete, a graph of pressure *vs*. volume will be displayed. To examine the data pairs on the displayed graph, tap any data point. As you tap each data point, the pressure and volume values are displayed to the right of the graph. Record the pressure and volume data values in your data table.

6. Based on the graph of pressure *vs*. volume, decide what kind of mathematical relationship exists between these two variables, direct or inverse. To see if you made the right choice:

   a. Click or tap Graph Options, , and choose Apply Curve Fit.

b. Select Power as the curve fit and Dismiss the Curve Fit box. The curve fit statistics are displayed for the equation in the form

$$y = ax^b$$

where x is volume, y is pressure, a is a proportionality constant, and b is the exponent of x (volume) in this equation. **Note**: The relationship between pressure and volume can be determined from the value and sign of the exponent, b.

c. If you have correctly determined the mathematical relationship, the regression line should very nearly fit the points on the graph (that is, pass through or near the plotted points).

d. Rescale the axes on your graph by clicking or tapping Graph Options, . Choose Edit Graph Options and set the x-axis to display 0 to 25 mL and the y-axis to display 0 to 300 kPa. Dismiss the Graph Options box.

e. (optional) Export, download, or print the graph with the curve fit displayed.

7. With the best-fit curve still displayed, proceed directly to the Processing the Data section.

DATA AND CALCULATIONS

Volume (mL)	Pressure (kPa)	Constant, *k* (P / V or P • V)

PROCESSING THE DATA

1. With the best-fit curve still displayed, click or tap Graph Options, , and turn on Interpolate. Dismiss the box and click the graph to interpolate. Move along the regression line until the volume value is 5.0 mL. Note the corresponding pressure value. Now move to the point where the volume value is doubled (10.0 mL). What does your data show happens to the pressure when the volume is *doubled*? Show the pressure values in your answer.

2. Using the same technique as in Question 1, what does your data show happens to the pressure if the volume is *halved* from 20.0 mL to 10.0 mL? Show the pressure values in your answer.

3. Using the same technique as in Question 1, what does your data show happens to the pressure if the volume is *tripled* from 5.0 mL to 15.0 mL? Show the pressure values in your answer.

4. From your answers to the first three questions *and* the shape of the curve in the plot of pressure *vs*. volume, do you think the relationship between the pressure and volume of a confined gas is direct or inverse? Explain your answer.

5. Based on your data, what would you expect the pressure to be if the volume of the syringe was increased to 40.0 mL? Explain or show work to support your answer.

6. Based on your data, what would you expect the pressure to be if the volume of the syringe was decreased to 2.5 mL? Explain or show work to support your answer.

7. What experimental factors are assumed to be constant in this experiment?

8. One way to determine if a relationship is inverse or direct is to find a proportionality constant, k, from the data. If this relationship is direct, $k = P/V$. If it is inverse, $k = P\bullet V$. Based on your answer to Question 4, choose one of these formulas and calculate k for the seven ordered pairs in your data table (divide or multiply the P and V values). Show the answers in the third column of the Data and Calculations table.

9. How *constant* were the values for k you obtained in Question 8? Good data may show some minor variation, but the values for k should be relatively constant.

10. Using P, V, and k, write an equation representing Boyle's law. Write a verbal statement that correctly expresses Boyle's law.

EXTENSION

1. To confirm that an inverse relationship exists between pressure and volume, a graph of pressure *vs. reciprocal of volume* (1/volume) may also be plotted. To do this, it is necessary to create a new column of data, reciprocal of volume, based on your original volume data:

   a. Click or tap More Options, ⋯, in the Volume column header in the table. Choose Add Calculated Column.
   b. Enter **1/volume** as the Name and **1/mL** as the Units.
   c. Click or tap Insert Expression and choose A/X as the expression.
   d. Enter **1** as Parameter A and select Volume as the Column.
   e. Click or tap Apply.

2. Plot a best-fit regression line on your graph of pressure *vs.* 1/volume:

   a. Click or tap Graph Options, 📈, and choose Edit Graph Options.
   b. Enter **0** as the value for both the Left value for the x-axis and the Bottom value for the y-axis.
   c. Dismiss the Graph Options box. Your graph should now include the origin (0,0).
   d. Click or tap Graph Options, 📈, and choose Apply Curve Fit.
   e. Select Linear as the curve fit and Dismiss the Curve Fit box. The linear-regression statistics are displayed in the form:

   $$y = mx + b$$

   where x is 1/volume, y is pressure, m is a proportionality constant, and b is the y-intercept.

   f. If the relationship between P and V is an inverse relationship, the graph of pressure *vs.* 1/volume should be direct; that is, the curve should be linear and pass through (or near) the origin. Examine your graph to see if this is true for your data.

Graph Matching

One of the most effective methods of describing motion is to plot graphs of position, velocity, and acceleration *vs.* time. From such a graphical representation, it is possible to determine in what direction an object is going, how fast it is moving, how far it traveled, and whether it is speeding up or slowing down. In this experiment, you will use a motion detector to determine this information by plotting a real-time graph of *your* motion as you move across the classroom.

The motion detector measures the time it takes for a high-frequency sound pulse to travel from the detector to an object and back. Using this round-trip time and the speed of sound, the distance to the object is calculated. This is the position of the object relative to the sensor. The change in position is then used to calculate the object's velocity and acceleration. All of this information can be displayed in a graph. A qualitative analysis of the graphs of your motion will help you develop an understanding of the concepts of kinematics.

OBJECTIVES

- Analyze the motion of a student walking across the room.
- Predict, sketch, and test position *vs.* time kinematics graphs.
- Predict, sketch, and test velocity *vs.* time kinematics graphs.

CHOOSE A METHOD

Method 1: Bluetooth Connection–Use Method 1 if you are using a mobile device, such as a tablet or a phone, and connecting to a Go Direct Motion via Bluetooth. You will hold the motion detector and measure your position and velocity relative to a wall.

Method 2: USB Connection–Use Method 2 if you are using a computer or Chromebook, and are connecting the motion detector via USB. You will measure your position and velocity relative to a stationary motion detector.

MATERIALS

Required for *both* Method 1 (Bluetooth connection) and Method 2 (USB connection)

Graphical Analysis app
Go Direct Motion
meter stick
masking tape

Required for Method 1 *only* (Bluetooth connection)

mobile device

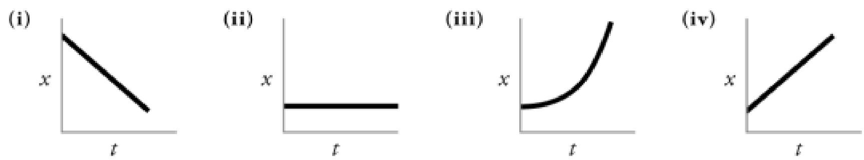
Required for Method 2 *only* (USB Connection)

computer or Chromebook

PRELIMINARY QUESTIONS

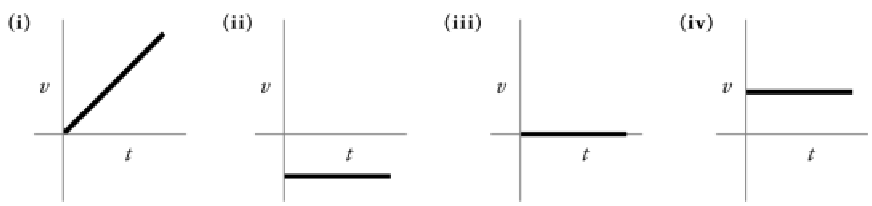
1. Below are four position *vs.* time graphs labeled (i) through (iv). Identify which graph corresponds to each of the following situations and explain why you chose that graph.

    a. An object at rest
    b. An object moving in the positive direction with a constant speed
    c. An object moving in the negative direction with a constant speed
    d. An object that is accelerating in the positive direction, starting from rest



2. Below are four velocity *vs.* time graphs labeled (i) through (iv). Identify which graph corresponds to each of the following situations. Explain why you chose that graph.

    a. An object at rest
    b. An object moving in the positive direction with a constant speed
    c. An object moving in the negative direction with a constant speed
    d. An object that is accelerating in the positive direction, starting from rest



PROCEDURE

Method 1 Bluetooth Connection

Part I Preliminary Experiments

1. Find an open area at least 2 m long in front of a wall. Use short strips of masking tape on the floor to mark distances of 0.5 m, 1 m, 1.5 m, and 2 m from the wall. You will be measuring your position from the motion detector in your hands to the wall.

2. Launch Graphical Analysis. Connect the motion detector to your mobile device.

3. Click or tap Mode to open Data Collection Settings. Change End Collection to 5 s. Click or tap Done.

4. Monitor the position readings and practice walking toward the wall holding the motion detector and mobile device. During data collection, the sensor portion of the motion detector should always point directly at the wall as shown in Figure 1. Sometimes you will have to walk backwards. Confirm that the position values make sense as you move back and forth.

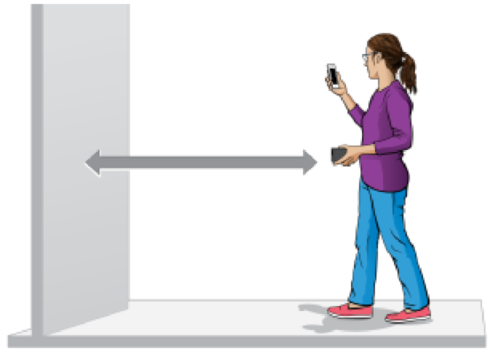


Figure 1

5. Make a graph of your motion while you walk away from the wall with constant velocity. To do this, stand about 0.5 m from the wall and click or tap Collect to start data collection. Slowly walk backward away from the wall after data collection begins.

6. Examine the graph. Sketch a prediction of what the position *vs.* time graph will look like if you walk faster. Check your prediction with the motion detector. Start data collection when you are ready to begin walking. **Note**: The previous data set is automatically saved.

Part II Position *vs.* Time Graph Matching

7. Click or tap Graph Options, 📈, and choose Add Graph Match. Choose Position. A position target graph is displayed for you to match.

8. Describe how you would walk to reproduce the target graph.

9. To test your prediction, choose a starting position. Start data collection, then walk in such a way that the graph of your motion matches the target graph on the screen.

10. If you were not successful, start data collection again when you are ready to begin walking. Repeat this process until your motion closely matches the graph on the screen. Export, print, or sketch the graph with your best attempt showing both the target graph and your motion data.

11. To perform a second position graph match, click or tap Graph Options, 📈, choose Add Graph Match, and then Position. Repeat Steps 8–10.

12. Answer the Analysis questions for Part II before proceeding to Part III.

Part III Velocity *vs.* Time Graph Matching

13. Graphical Analysis can also generate random target velocity graphs for you to match. Click or tap Graph Options, 📈, and choose Add Graph Match. Choose Velocity to view a velocity target graph.

14. Describe how you would walk to produce this target graph. Sketch or print a copy of the graph.

15. To test your prediction, choose a starting position and stand at that point. Start data collection, then walk in such a way that the graph of your motion matches the target graph. It is more difficult to match the velocity graph than the position graph.

16. If you were not successful, start data collection again when you are ready to start walking. Repeat this process until your motion closely matches the graph on the screen. Export, print, or sketch the graph with your best attempt showing both the target graph and your motion data.

17. To perform a second velocity graph match, click or tap Graph Options, 📈, choose Add Graph Match, and then Velocity. Repeat Steps 14–16.

18. Remove the masking tape from the floor.

19. Proceed to the Analysis questions for Part III.

Method 2 USB Connection with Computers or Chromebooks

Part I Preliminary Experiments

1. Place the motion detector so that it points toward an open space at least 2 m long. Use short strips of masking tape on the floor to mark distances of 0.5 m, 1 m, 1.5 m, and 2 m from the motion detector.

2. Launch Graphical Analysis. Connect the motion detector to your Chromebook or computer.

3. Click or tap Mode to open Data Collection Settings. Change End Collection to 5 s. Click or tap Done.

4. Monitor the position readings and practice walking toward the motion detector. Sometimes you will have to walk backwards. Confirm that the position values make sense as you move back and forth.

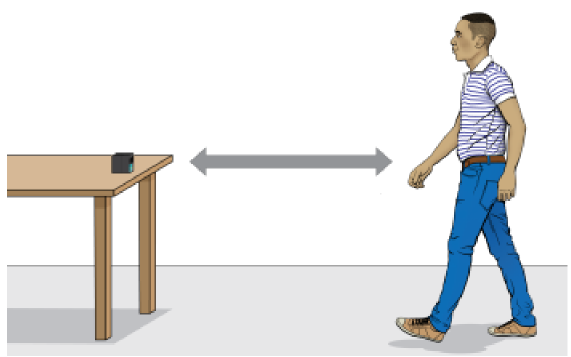


Figure 2

5. Make a graph of your motion while you walk away from the motion detector with constant velocity. To do this, stand about 0.5 m from the motion detector and click or tap Collect to start data collection. Slowly walk backward away from the motion detector after data collection begins.

6. Examine the graph. Sketch a prediction of what the position *vs.* time graph will look like if you walk faster. Check your prediction with the motion detector. Start data collection when you are ready to begin walking. **Note**: The previous data set is automatically saved.

Part II Position *vs.* Time Graph Matching

7. Click or tap Graph Options, 📈, and choose Add Graph Match. Choose Position. A position target graph is displayed for you to match.

8. Describe how you would walk to reproduce the target graph.
9. To test your prediction, choose a starting position. Start data collection, then walk in such a way that the graph of your motion matches the target graph on the screen.
10. If you were not successful, start data collection again when you are ready to begin walking. Repeat this process until your motion closely matches the graph on the screen. Export, print, or sketch the graph with your best attempt showing both the target graph and your motion data.
11. To perform a second position graph match, click or tap Graph Options, , choose Add Graph Match, and then Position. Repeat Steps 8–10.
12. Answer the Analysis questions for Part II before proceeding to Part III.

Part III Velocity *vs.* Time Graph Matching

13. Graphical Analysis can also generate random target velocity graphs for you to match. Click or tap Graph Options, , and choose Add Graph Match. Choose Velocity to view a velocity target graph.
14. Describe how you would walk to produce this target graph. Sketch or print the graph.
15. To test your prediction, choose a starting position and stand at that point. Start data collection, then walk in such a way that the graph of your motion matches the target graph. It is more difficult to match the velocity graph than the position graph.
16. If you were not successful, start data collection when you are ready to start walking again. Repeat the process until your motion closely matches the graph. Export, print, or sketch the graph with your best attempt showing both the target graph and your motion data.
17. To perform a second velocity graph match, click or tap Graph Options, , choose Add Graph Match, and then Velocity. Repeat Steps 14–16.
18. Remove the masking tape from the floor.
19. Proceed to the Analysis questions for Part III.

ANALYSIS

Part II Position *vs.* Time Graph Matching

1. Describe how you walked for each of the graphs that you matched.
2. Explain the significance of the slope of a position *vs.* time graph. Include a discussion of positive and negative slope.
3. What type of motion is occurring when the slope of a position *vs.* time graph is zero?
4. What type of motion is occurring when the slope of a position *vs.* time graph is constant?
5. What type of motion is occurring when the slope of a position *vs.* time graph is changing? Test your answer to this question using the motion detector.

Part III Velocity *vs.* Time Graph Matching

6. Describe how you walked for each of the graphs that you matched.

7. What type of motion is occurring when the slope of a velocity *vs*. time graph is zero?

8. What type of motion is occurring when the slope of a velocity *vs*. time graph is not zero? Test your answer using the motion detector.

EXTENSIONS

1. Create a graph-match challenge. Click or tap File, 🗋, and choose New Experiment. Click or tap Sensor Data Collection. Set up data-collection to end after 5 seconds. Click or tap View Options, ⊞, and choose 1 Graph. Click or tap Graph Options, 📈, and choose Add Prediction. Use the Prediction tool to sketch a position *vs*. time graph. Click or tap Save. Challenge another student to match your graph. Have the other student challenge you in the same way.

2. Create a velocity *vs*. time challenge in a similar manner.