11. Motion Graphs

Follow the Leader

Objectives

In this activity students discover the spatial meaning of such terms as "position," "fixed reference point," and "frame of reference." Students use the motion sensor to measure their motion and then kinesthetically match their motion with the motion represented on a position versus time graph. This activity prepares students for the concept of velocity, because it provides background experience with direction of motion as well as speed.

Students investigate their position and observe how it changes while:

- Recognizing position as the distance and direction of an object relative to a fixed point of reference (or frame of reference)
- Recognizing motion as the change in an object's position
- Relating the frame of reference to the location of the observer
- Moving back and forth relative to the motion sensor, in order to match the pattern of their motion with the pattern on a target graph of position versus time
- Using math skills to analyze motion represented by a specific position versus time graph
- Gaining skills in using scientific measurement tools, the motion sensor, as well as the graphing capability of a computer to represent and analyze data

Procedural Overview

Students gain experience conducting the following procedures:

- Setting up the equipment and work area to measure the position of a moving object
- Walking backward and forward before the motion sensor to match a graph of position versus time as plotted by another student
- Relate slope of a line with rate of speed, given distance and time

Time Requirement

■ Introductory discussion and lab activity, Part 1 – Making predictions	50 minutes
■ Lab activity, Part 2 – Follow the leader	50 minutes
■ Lab activity, Part 3	50 minutes
■ Analysis	50 minutes

Materials and Equipment

For teacher demonstration:

- Data collection system
- Motion sensor
- Reflector (optional)

For each student or group:

- Data collection system
- Motion sensor
- Reflector (optional)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Reference points commonly used in daily life to describe distances and directions
- Process skills such as using a meter stick or ruler to measure the length of objects, or distances from one point to another
- Be able to read and interpret a coordinate graph
- The SI unit used to measure length is meters.
- The basics of using the data collection system.

Related Labs in This Guide

Labs conceptually related to this one include:

- Speed and Velocity
- Mapping the Ocean Floor

Using Your Data Collection System

Students use the following technical procedures in this activity. The instructions for them are in the appendix that corresponds to your PASCO data collection system (identified by the number following the symbol: "�"). Please make copies of these instructions available for your students.

- Starting a new experiment on the data collection system �(1.2)
- Connecting a sensor to the data collection system �(2.1)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)

- Displaying multiple data runs in a graph �(7.1.3)
- Saving your experiment �(11.1)
- Printing your experiment �(11.2)

Background

The terms “distance,” “position,” and “distance traveled” are often used interchangeably in everyday language. This can cause confusion when students begin their study of motion because the terms often have very different meanings when they are used in science. (Motion is a change in position relative to a frame of reference.)

“Distance” refers to the amount of space between points. In other words, it is a length. “Position” refers to the location of an object relative to a frame of reference. Position includes both direction and distance from the frame of reference. If you tell someone the *distance* to your house, you might say “five kilometers” (5 km). If you tell someone the *position* of your house, you might say “5 kilometers (km) east of the mall.” In this description the distance is *5 km*, the direction is *east,* and the frame of reference is *the mall*.

“Distance traveled” is the total distance required to get from one position to another. Assuming that you travel on a straight road to the mall, your distance traveled is 5 km and your position is 5 km west of your home. Now, imagine that you turn around and travel from this position toward your house, going a distance of 2 km. Your distance traveled is then 7 km (5 km + 2 km), but your position is 3 km (5 km – 2 km) east of your house. In this example the distance is *3 km*, the direction is *west*, and the frame of reference is the location of your house.

“Frame of reference” refers to the location of the observer while measurements of position or motion are made. For example, if the observer is in a moving car, the car is not moving relative to the observer. Therefore, the observer in the car could say that the position of the car is *constant*. However, if the observer is standing on the side of the road, the car is moving relative to the observer. Therefore, the observer on the side of the road would say that the position of the car is *changing*.

Pre-Lab Discussion and Activity

Post the following questions on the board before the students enter the classroom:

- Where do you live?
- Where are you right now?
- What is motion?
- What does position mean?
- What does distance mean?
- What does distance traveled mean?

Direct the students to “Thinking About the Question.” Instruct the students to use a frame of reference when discussing the first two questions. Have students discuss these questions in their lab groups. After a few minutes, ask the student lab groups to share some of their answers with the class. If necessary, direct students’ attention toward including both distance and direction relative to a frame of reference. Record on the board the students' ideas about the meaning of position compared to distance traveled.

Demonstrate the use of the motion sensor to record position versus time. Show students how to walk toward and away from the motion sensor and the resulting position versus time graph. Show students what the graph looks like if the motion sensor loses its echolocation "target," and remind them to walk straight in front of the sensor's metal screen and avoid side-to-side motion. Demonstrate the use of a reflector to improve the ability of the motion sensor to "see" the object in motion.

Now direct the students to “Investigating the Question.”

Preparation and Tips

These are the materials and equipment to set up prior to the lab:

- Prepare ahead of time to demonstrate the use of the motion sensor. Show the students the round gold screen, and refer to it as the reference point. All motion will be measured relative to the reference point. Allow students to hear the clicking sound the motion sensor emits when it is collecting data. If you choose, you can explain to the students that the motion sensor sends out pulses of ultrasonic sound waves that reflect from an object and return to the sensor. Using the speed of ultrasonic sound waves and the time to and from the object, the software calculates the position of the object relative to the sensor. The motion sensor works like the sonar that dolphins and whale use.

- Make sure the selector switch on each motion sensor is set to “person” (broad beam) instead of “cart” (narrow beam).

- Be sure to supervise students as they set up their work area, so that they have a safe, clear path in which to move toward and back away from the motion sensor. Remove obstacles that the students may trip on.

- Each student group needs to have one student chosen to be the "walker" in Part 2 and Part 3 of the activity, to serve as the "leader" for the other members to follow. You may pre-select these students or have them volunteer in their groups. Every student in each group will have the chance to make at least one motion graph.

- Make sure that students understand that the followers need to be able to see the graph of the leader while they are walking, so they must set up their work area to account for this.

- Students need to complete their position match walks within 10 to 20 seconds of beginning data collection.

- Circulate among the groups as they work. Check to see that they are successfully collecting motion data. If you notice “spikes” in their graphs, the student volunteering as the "walker" may be inadvertently stepping outside of the narrow cone of sound waves. Also, the motion sensor may be too high or too low for the particular student. The sensor “loses” the target of its echolocation and instead bounces the sound waves off the next nearest object, which may be the back wall of the classroom.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Make sure there is a clear path in front of the motion sensor.
- Do not allow obstacles to obstruct students' path or they may trip.

Driving Question

How do you know where you are going?

Thinking about the Question

Describing your location, or position, is based upon describing the distance between you and some fixed reference point. When you change your position, you experience motion.

If you have ever ridden a rollercoaster at an amusement park, you have probably used the ground as your fixed reference point. How did you know you were getting higher? If the rollercoaster went through loops or spirals, how could you tell if you were upside down? Sometimes people who are scared during the ride close their eyes. Do you think this might help? Why or why not? Regardless of whether the rollercoaster was fun or scary, the ride is eventually over. How would you know that the rollercoaster had stopped? Would it be possible to use a fixed reference point other than the ground?

> Students may say that closing their eyes during the ride prevents them from being able to tell when they are upside down because they lack a reference point such as the ground, or they would not be able to see the sky at their feet. Students may describe using the horizon or the sky as a fixed reference point. They may also describe using another landmark in an amusement park, such as a different rollercoaster or attraction that is visible. When the ride comes to a stop, students may describe using some aspect of the ride's structure as the reference point, as well as or instead of the ground.

Discuss with your lab group members how to compare where you are right now to where you live. How do you use a fixed reference point to help in this comparison? What does "frame of reference" mean? Do you need to use a direction and a distance? What is motion? How do you know if an object is in motion?

> Answers will vary. Students may refer to knowing how many miles away they live from school, and they may know the compass direction they travel to go from home to school and vice versa. They may discuss using familiar landmarks such as buildings, parks, or particular streets as reference points to use as comparisons. Students may use the term "landmark" in their description of "frame of reference." Students should recognize that they need to include both direction and distance in order to describe motion fully. They should recognize that a change in position or distance from a fixed reference point is used to tell if an object is in motion.

Sequencing Challenge

Note: This is an optional ancillary activity that may be omitted.

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

2/3	1	3/2	4	5
Determine how far away from the motion sensor 50 cm is, so the walker knows where to begin.	Make sure that each lab group member is aware of safety rules and procedures for this lab.	Determine the maximum distance away from the motion sensor the walker may move.	Start recording position versus time data.	Begin walking backward and forward when the clicking sound of the motion sensor becomes audible.

Investigating the Question

Note: When students see the symbol "�" with a superscripted number following a step, they should refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There they will find detailed technical instructions for performing that step. Please make copies of these instructions available for your students.

Part 1 – Making predictions

1. ☐ The job of the "walker" in this activity is to walk back and forward in front of the motion sensor. The walker's position relative to the motion sensor will change throughout this activity. Write your predictions about the walker for the following:

   a. How will a graph of position versus time change when the walker moves closer to the fixed reference point (the motion sensor)?

   b. How will the graph of position versus time change when the walker moves away from the fixed reference point?

   c. If the walker's distance from the fixed reference point does not change, how would this appear on the graph of position versus time?

   Students should predict that the slope of the line will decrease or go down as the walker moves closer. They should predict that the slope of the line will increase or go up as the walker moves away. They should predict that the slope of the line will be zero, or flat, while the walker's distance does not change. Some students may erroneously predict that the graph of position will drop to zero when the walker's position does not change.

2. ☐ Write your predictions for the following:

   Suppose a walker begins two meters away from the reference point and walks slowly toward it until stopping at 0.5 meters away from it. Then a second walker takes the same walk, but walks much more quickly. How would the graphs of these two motions compare? How would they differ? You may sketch your predictions or describe them using words.

   Students should predict that both the slow walker and the fast walker would have a graph that goes down (or has a negative slope). They should predict that the faster walker will have a graph that goes down faster (with a steeper negative slope). Students may also predict that the total time elapsed for the faster walker is less than for the slow walker.

Part 2 – Follow the leader

3. ☐ Start a new experiment on the data collection system. �(1.2)

4. ☐ Connect the motion sensor to the data collection system. �(2.1)

5. ☐ Display Position on the y-axis of a graph with Time on the x-axis. �(7.1.1)

6. ☐ Change the sampling rate to take position measurements 5 times per second (5 Hz). �(5.1

7. ☐ Select one student to be the first walker. This person will be the leader for this part of the activity. The walker should stand in front of the motion sensor at a distance of 50 cm from the metal screen. Why is it important to choose one particular fixed object to measure the distance from?

It is important to choose one particular fixed object to measure distance from because the definition of motion is the change in distance from something to a fixed reference point, as measured by a particular observer in a particular frame of reference. The metal screen of the sensor in this case is our fixed reference point.

8. ☐ Start data recording. �(6.2)

9. ☐ The walker should now move as follows:

   a. Stand still for 2 seconds

   b. Back away from the motion sensor slowly for 6 seconds

   c. Stop and stand still for 2 seconds

10. ☐ Stop data recording. �(6.2)

11. ☐ If necessary, adjust the scale of the graph to show all data. �(7.1.2) The pattern on the graph shows the motion of the leader. The other members of your lab group will each try to match the position graph of the leader, walking the same distances in the same amounts of time.

12. ☐ Select a new walker to follow the leader. The new walker should stand in front of the motion sensor at a distance of 50 cm from the metal screen.

13. ☐ Start data recording. �(6.2)

14. ☐ The new walker should now move in such a way as to follow the motion of the leader, matching the leader's position graph as closely as possible.

15. ☐ At the end of the 10 seconds stop data recording. �(6.2)

16. ☐ Hide the last walker's data run so only the leader's graph shows. �(7.1.1)

17. ☐ Select the next walker to follow the leader. The next walker should stand in front of the motion sensor at a distance of 50 cm from the metal screen.

18. ☐ Start data recording. �(6.2)

19. ☐ The next walker should now move in such a way as to follow the motion of the leader, matching the leader's position graph as closely as possible.

20. ☐ At the end of the 10 seconds stop data recording. �(6.2)

21. ☐ Hide the last walker's data run so only the leader's graph shows. �(7.1.1)

22. ☐ Repeat the activity for each member of your lab group.

23. ☐ Save your experiment according to your teacher's instructions. �(11.1)

Part 3 – Matching position

24. ☐ Start a new experiment on the data collection system. �(1.2)

25. ☐ Display Position on the y-axis of a graph with Time on the x-axis. �(7.1.1)

26. ☐ Change the sampling rate to take position measurements 5 times per second (5 Hz). �(5.1

27. ☐ Select one student to be the first walker. This person will be the leader for this part of the activity.

28. ☐ The leader should stand in front of the motion sensor at a distance of his/her choice, but no closer than 15 cm from the metal screen.

29. ☐ Start data recording. �(6.2)

30. ☐ The leader should now begin moving slowly and steadily toward or away from the motion sensor, standing completely still at least once during the walk. The entire walk should take between 10 and 20 seconds.

31. ☐ Stop data recording. �(6.2)

32. ☐ Select a new walker to follow the leader. The new walker should stand in front of the motion sensor at the same initial distance from the motion sensor at which the leader began. For an added challenge, group member should not watch the "leader's" movement while they are making the graph.

33. ☐ Start data recording. �(6.2)

34. ☐ The new walker should now move in such a way as to follow the motion of the leader, matching the leader's position graph as closely as possible.

35. ☐ As soon as the new walker has matched the position graph of the leader, stop data recording. �(6.2)

36. ☐ Hide the last walker's data run so only the leader's graph shows. �(7.1.1)

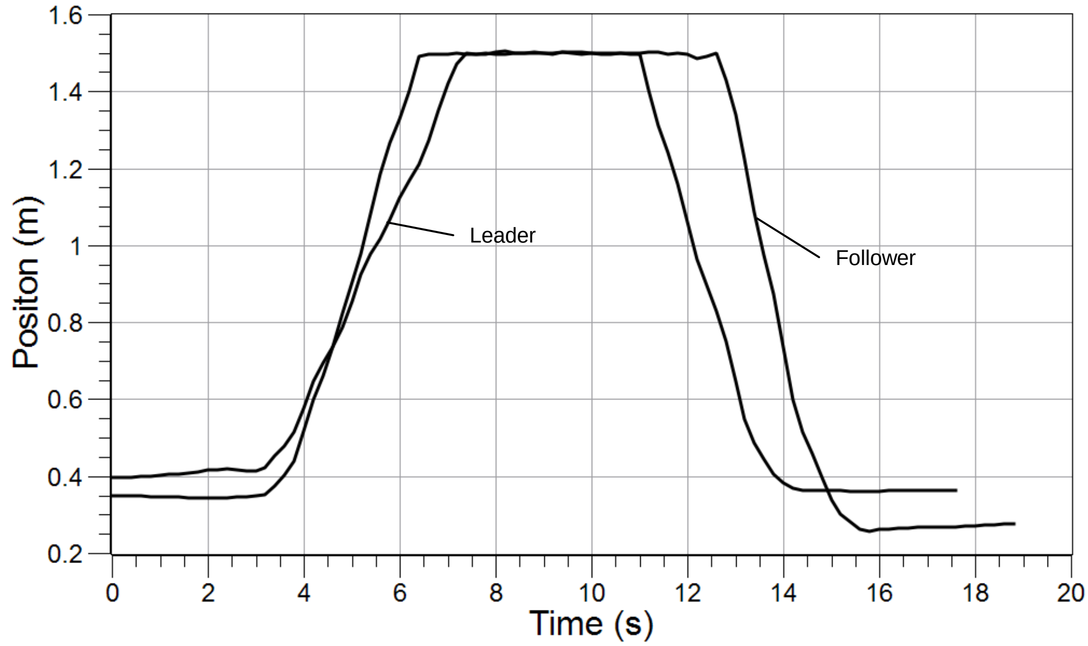
37. ☐ Repeat the activity for each member of your lab group.

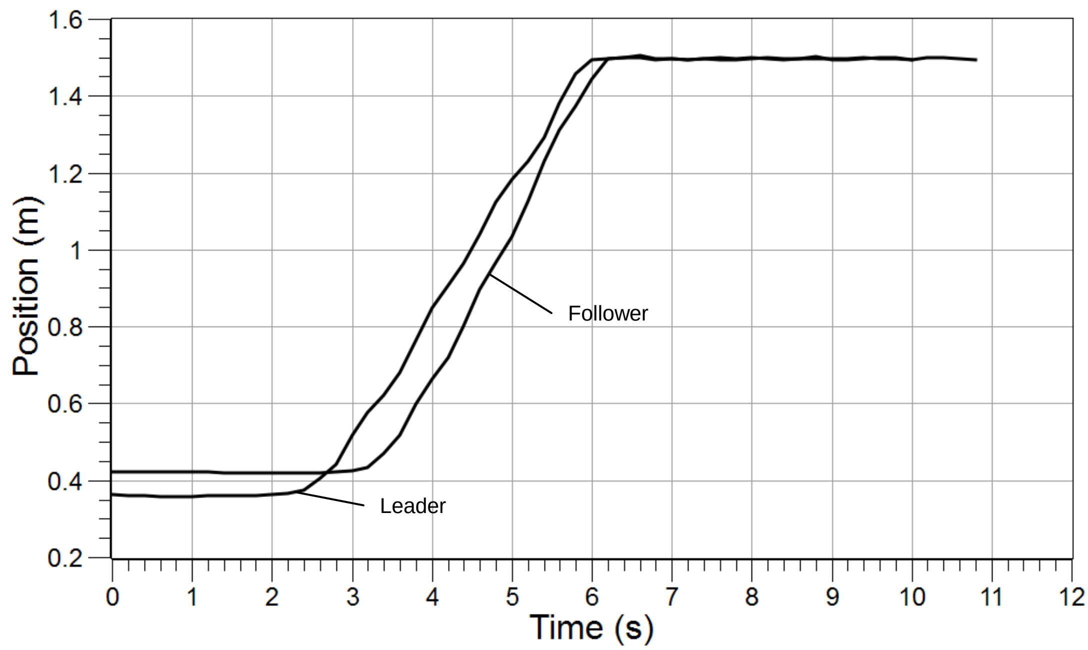
38. ☐ Save your experiment according to your teacher's instructions. �(11.1)

39. ☐ What did you observe about matching the leader's position graph? Write your observations in the space below.

Answers will vary. One student group answered as follows: It is harder to match the graph than it seems. The hardest part is knowing how fast to walk, and walking evenly. At first we could not get the slanted parts of our graphs to match the leader's position at all. It took several tries to get better at it. We discovered that taking very small steps helps to make the sloped parts smoother.

Sample Data





Answering the Question

Analysis

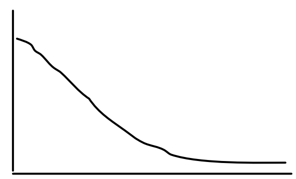
1. How did your predictions from Part 1 compare to the results in Part 2?

   Answers will vary. One group answered as follows: We predicted that the graphs would go down when the target moved closer to the reference point, and up when the target moved farther away from the reference point, and this turned out to be correct. However, when someone stops, their graph does not drop to zero, it just stays flat. If you look at the y-axis, you can tell how far away from the reference point they were when they stopped.

2. What does the slope, or steepness, of the graph tell you about the walker's motion?

The steepness or slope tells how fast or slow a target was moving. A steeper slope means the walker was going faster.

3. If you wanted to model a rollercoaster car coming to a stop at the end of the ride, the walker could represent the rollercoaster car, and the motion sensor could represent the boarding platform of the ride, where riders get on and off the rollercoaster. Describe or sketch the graph of the ride coming to a stop.



The graph looks like this. As the rollercoaster car slows down, its graph gets less steep. Then, once it stops, the graph is flat, or it has a slope of zero.

4. For Part 2, review your data carefully. Look at the position graph for the leader and each follower. �(7.1.3) Compare the motion of each follower individually to the motion of the leader. Select a data run that you think is a good example of the follower matching the leader's motion well. How did you make your decision? Describe what characteristics of the graphs you looked at to decide how well the follower matched the leader's position over time.

Answers will vary. One group answered as follows: When we looked at each graph compared to the leader's we looked at how close the follower's distance from the motion sensor at that second matched the leader's distance at the same second. Also, on the sloped part, we looked for the graph that was as close to parallel with the leader's graph as possible.

5. For Part 3, perform the same data analysis to compare each walker's motion to that of the leader. Choose one graph that you think is a good example of following the motion of the leader.

6. Get your teacher's permission to print out the example graph you have selected. �(11.2)

7. Write a thorough, detailed description of the motion of the two walkers. You may write your description on the graph print-out, or in the space below. You may find it helpful to label important points along the motion graph in order to help you refer to them (for example, point A, point B, point C, et cetera).

Answers will vary. One group answered as follows: At point A the person was standing still. They were 0.5 meters away from the reference point. They stood still for 2 seconds. At point B they started to move backward steadily and somewhat rapidly until the graph reached point C 3 seconds later. Then they stopped, and stood still for 2 seconds until the point we labeled D on our graph. They then walked toward the motion sensor for 2 seconds and stopped. We stopped recording data one second after that. At the end of the walk, they were about 1.8 meters away from the motion sensor.

8. From which frame of reference is this motion observed?

This motion was observed from the frame of reference of the motion sensor.

9. How could you have matched this position-time graph better?

Answers will vary. One group answered as follows: With more practice, we think we could do even better, because now we know how to do it, and we also know about how fast we would have to back away from the motion sensor. Also, we learned that it is really important to stand very still when you are supposed to be stopped. We decided that we would like to discuss the motion and describe it first before trying to follow the leader to match a position graph the next time. It is helpful to know the distance we are supposed to walk and the amount of time to cover the distance.

Multiple Choice

Circle the best answer or completion to each of the questions or incomplete statements below.

1. In the SI System of measurement, distance is measured in:

   A. Feet
   B. Meters
   C. Miles

2. A change in position relative to a fixed reference point is known as:

   A. Motion
   B. Distance
   C. Speed

3. Another term for how steep a line on a graph appears is:

   A. Slope
   B. Rise
   C. Run

4. In order to get information about their motion as they take off from the launch pad at Cape Canaveral, the astronauts on board the Space Shuttle compare their position to:

   A. The military and civilian aircraft flying nearby
   B. The ground beneath them
   C. The other astronauts in the cockpit with them

5. On a position versus time graph of motion, the fastest motion toward or away from the fixed reference point is where the graph:

   A. Remains flat and horizontal for a period of time
   B. Has the steepest slope
   C. Has the least steep non-zero slope

True or False

Enter a "T" if the statement is true or an "F" if it is false.

___T___ 1. In order to know if an object's position has changed, you must measure its distance to a fixed reference point.

___F___ 2. If you are riding in a car that is traveling south at 60 km/h, your position is changing compared to the car.

___T___ 3. If you are riding in a car that is traveling south at 60 km/h, your position is changing compared to the road.

___T___ 4. To say that you are stopped means that your distance from some fixed reference point is not changing.

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

distance	fixed frame of reference	motion	x-axis	y-axis

1. A measurement of __distance__ is also a measurement of length.

2. On a graph of position versus time, position is plotted on the __y-axis__, while time is plotted on the __x-axis__.

3. An object whose position is changing relative to a fixed reference point is said to be in __motion__.

4. The round gold screen on the motion sensor serves as a __fixed frame of reference__ for determining motion.

Further Investigations

Use the predict tool �(7.1.12) in the software to create an original position-time graph, then ask another student group to try to match it!

Note: If you use the Xplorer GLX as your data collection system, be aware that this device does not have a predict tool.

Use the predict tool in the software to draw a large circle in the middle of the graph. Investigate the possibility of matching this position-time graph.

Research the mathematical definitions of function and the vertical line test for a function. Use the predict tool in the software to show that it is impossible to match the position-time graph that fails the vertical line test.

Rubric

For scoring students' accomplishments and performance in the different sections of this laboratory activity, refer to the Activity Rubric in the Introduction.