Lesson 4: Measuring Velocity and Acceleration (2 Days)

☐ Getting Started

In the previous lesson you were given some data points, and you used them to draw graphs and calculate the velocity and acceleration of an object at different times. In this lesson, you will gather your own data, draw similar graphs, and do similar calculations. As you will soon see, calculating velocity and acceleration can be more challenging when you have to collect your own data.

Stuff You Need

- ✓ calculator
- ✓ timer that can record laps* (Activity 1 - optional)
- ✓ tape measure (kit)

Ideas to Think About

- What is the relationship between velocity and acceleration?
- What is meant by the terms *average velocity* and *average acceleration*?

Things to Know

- Remember that velocity is the rate of change of the *position* (distance) of an object over time, and acceleration is the rate of change of the *velocity* of an object with respect to time.

Activities

☐ Activity 1: Investigating Velocity and Acceleration

In this activity, you will design and conduct an investigation about the movement of objects, similar to the thought experiments you read about in the last lesson.

When scientists conduct experiments, they must be extremely accurate in their data collection and analysis. As the scientist in this investigation, your job will be to measure distance and time as accurately as you can.

Use the "Investigating Velocity and Acceleration" sheet to guide your planning and the "Data Collection" sheet to record your findings.

Day 2

☐ Activity 2: Calculating Average Velocity

Velocity tells you how long it takes for a moving object to get from one position to another in a given direction. It is measured in meters per second (m/s). While today's activity focuses only on calculating your object's velocity based on its speed, remember that the velocity of an object also changes if its *direction* changes. Follow the steps on the "Average Velocity" sheet to calculate and graph the average velocity of your moving object.

☐ Activity 3: Calculating Acceleration

A change in the velocity of an object is called acceleration. Now that you know the velocity of your moving object, you can find its acceleration. You'll need to transfer the elapsed and lap times, as well as the velocities you calculated in the previous activity, to the "Average Acceleration" sheet. Then follow the rest of the steps on the activity sheet to find out how much your object accelerated.

As you do your calculations, keep in mind that you are trying to figure out the *rate of change* in the velocity of your object. That is, how much did the velocity change between each time marker in your investigation? This number could be very small depending on how your experiment was designed! Also remember that your object may have gone faster or slower between time markers. If it slowed down, your acceleration will be negative.

☐ Wrapping Up

Review what you have learned about velocity, acceleration, and all of their related terms. In the next lesson you will continue to explore balanced forces.

Investigating Velocity and Acceleration

Carrying out an investigation requires planning. Here are some things you'll need to decide before you begin:

1. **What moving object will you observe?** You can choose a walking or running human, a rolling ball, a bicycle or skateboard with a rider, a toy car, or any other object you want, as long as it can move a fair distance.

2. **What distance (in meters) do you want the object to travel?** It will need to be far enough for you to be able to record its time at four points during the experiment. For example, if you have someone run a distance of forty meters, you could record her time every ten meters. This would give you five data points to work with: a starting line, a finish line, and three markers in between.

3. **How will you measure and mark distances?** Remember that the distances will need to be equal.

4. **How will you time the person or object?** (You will need a smart phone, fitness watch, or stopwatch that can record lap times. As an alternative, you can use four helpers with their own timers so they can call out the times while someone writes them down.)

Now follow these steps:

1. Gather your materials: your moving object, the distance markers, a tape measure (or the measuring tape from your science kit), timing device(s), any helpers, and the "Data Collection" form.
2. Set up your experiment by measuring out the starting line, finish line, and the equally spaced intervals in between where you will be noting the time.
3. Conduct a practice investigation and record the data on the data collection form. You have two options for recording your time data. Use "Elapsed Time" if you have a continuously running timer. Use "Lap Time" if your timer records only the number of seconds between markers. A sample chart is included in the answer key. Ask your parents if you need help deciding which column to use.
4. Did the practice run go smoothly? If not, correct any problems you had and test again.
5. Do your final investigation and record the data.

Data Collection

Practice 1

	Distance (meters)	Elapsed Time (seconds)	Lap Time (seconds)
Start			
Marker 1			
Marker 2			
Marker 3			
Finish			

Practice 2

	Distance (meters)	Elapsed Time (seconds)	Lap Time (seconds)
Start			
Marker 1			
Marker 2			
Marker 3			
Finish			

FINAL

	Distance (meters)	Elapsed Time (seconds)	Lap Time (seconds)
Start			
Marker 1			
Marker 2			
Marker 3			
Finish			

Average Velocity

Instructions: Use the final data you recorded in the table in Activity 1 to calculate your object's velocity between markers. Actually, you will be calculating its average velocity, because in real life things don't normally move at a perfectly uniform rate.

In the last lesson, you learned how to find an object's average velocity using the slope of a line on a graph. Today you'll be using this formula:

$$\text{average velocity} = \frac{\text{ending position (ending distance)} - \text{starting position (starting distance)}}{\text{ending time} - \text{starting time}}$$

Calculations

1. Calculate the average velocity of your moving object from zero seconds to your first time measurement. Round your numbers to the nearest tenth. NOTE: If you recorded lap times, you will not need to subtract beginning and ending times. You will just use the lap time. If you recorded elapsed time, you will subtract the beginning and end times as shown in the formula. (Hint: Your ending position will be Marker 1, your starting position will be 0. Your ending time will be Marker 1, your starting time will be 0.)

2. Calculate the average velocity of your moving object from your first time measurement to your second time measurement.

3. Calculate the average velocity of your moving object from your second time measurement to your third time measurement.

4. Calculate the average velocity of your moving object from your third time measurement to your fourth time measurement (the finish line).

Follow these steps to create a distance-time graph:

1. Use "Time (in Seconds)" for your x-axis and "Distance (in Meters)" for your y-axis. Then decide on the scale of the graph as you did in the last lesson when you created your velocity graphs.

2. Plot the distance and time data you recorded on your final data collection chart. NOTE: If you recorded lap time, you will need to calculate the elapsed time for the three markers and the finish line before you can graph your data. Then connect the dots.

3. Did your object move at a constant velocity or an irregular velocity? How do you know?

Average Acceleration

	Elapsed Time (s)	Lap Time (s)	Velocity (m/s)
Start	0	0	0
Marker 1			
Marker 2			
Marker 3			
Finish			

Instructions: Copy your final time data and your velocity calculations from Activity 2 into the the table. Use this information to calculate and graph your object's acceleration. Again, you will actually be calculating your object's average acceleration, because in real life things don't normally move at a perfectly uniform rate.

In the last lesson, you learned how to find an object's average acceleration using the slope of a line on a graph. Today you'll be using this formula:

$$\text{average acceleration} = \frac{\text{ending velocity} - \text{starting velocity}}{\text{ending time} - \text{starting time}}$$

Calculations

1. Calculate the average acceleration of your moving object from zero seconds to your first time measurement. If your average accelerations are very small, round them to the nearest hundredth or thousandth so you can see the difference. NOTE: If you recorded lap times, you will not need to subtract beginning and ending times. You will just use the lap time. If you recorded elapsed time, you will subtract the beginning and end times as shown in the formula.(Hint: Your ending velocity will be Marker 1, your starting velocity will be 0. Your ending time will be Marker 1, your starting time will be 0.)

2. Calculate the average acceleration of your moving object from your first time measurement to your second time measurement.

3. Calculate the average acceleration of your moving object from your second time measurement to your third time measurement.

4. Calculate the average acceleration of your moving object from your third time measurement to your fourth time measurement (the finish line).

Create a Velocity-Time Graph

1. Use "Time (in Seconds)" for your x-axis and "Velocity (m/s)" for your y-axis. Use a scale that will best represent your data. For example, if your velocity calculations were less than 3 meters/second, consider using increments of fifths (0.2, 0.4, 0.6 m/s) on your y-axis.

2. Plot your data on the graph and connect the dots. Use elapsed time as your time data.

3. Did your object move at a constant acceleration or an irregular acceleration? How do you know?

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Lesson 4: Measuring Velocity and Acceleration (2 Days)

Getting Started

? Big Ideas

- What is the relationship between velocity and acceleration?
- What is meant by the terms *average velocity* and *average acceleration*?

Facts and Definitions

- Remember that velocity is the rate of change of the *position* (distance) of an object over time, and acceleration is the rate of change of the *velocity* of an object with respect to time.

Skills

- Know that a force has both direction and magnitude. (S)
- As a basis for understanding that the velocity of an object is the rate of change of its position, know that position is defined in relation to a standard reference point and a set of reference directions, the velocity of an object must be described by specifying both the direction and the speed of the object, average speed is the total distance traveled divided by the total time elapsed, and the speed of an object along the path traveled can vary. (S)
- Know how to solve problems involving distance, time, average velocity, and average acceleration. (S)
- Know that changes in velocity may be due to changes in speed, direction, or both. (S)

Introducing the Lesson

In today's lesson your child will design and conduct her own investigation involving the movement of objects. This lesson will help her further develop the skills of accurate data collection and analysis. It will also introduce her to the formulas for calculating average velocity and average acceleration mathematically rather than using the slope of a graph, as she did in the last lesson. Note that there is no reading for this lesson.

Activities

Activity 1: Investigating Velocity and Acceleration

In this activity, your child will design her own experiment and collect her own data. She will do a practice run, fix any problems, and then do a final run. Encourage her to be as accurate as she can with her data collection. She will be using this data to complete tomorrow's two activities. Here are two sample data charts, one using elapsed time and the other using lap time:

"Data Collection" Answer Key

[SAMPLE 1]

	Distance (meters)	Elapsed Time (seconds)	Lap Time (seconds)
Start	0	0	
Marker 1	5	3.8	
Marker 2	10	7.3	
Marker 3	15	10.5	
Finish	20	14	

[SAMPLE 2]

	Distance (meters)	Elapsed Time (seconds)	Lap Time (seconds)
Start	0		0
Marker 1	5		3.8
Marker 2	10		3.5
Marker 3	15		3.2
Finish	20		3.5

Day 2

Activity 2: Calculating Average Velocity

Sample calculations and a sample graph for this activity are provided. Your child's answers will be different. In assessing your child's activity, make sure that she is using the correct formula and units of measurement for distance (meters), time (seconds), and velocity (meters/second).

Answer Key:

Sample Calculations Using Distance and Elapsed Time

1) $\frac{5 - 0}{3.8 - 0} = \frac{5}{3.8} = 1.3$ m/s

2) $\frac{10 - 5}{7.3 - 3.8} = \frac{5}{3.5} = 1.4$ m/s

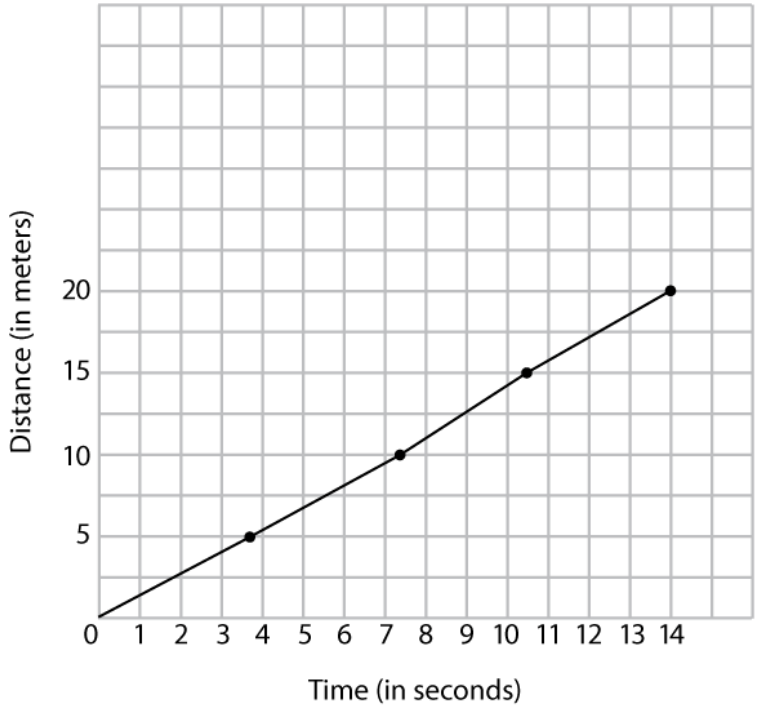
3) $\frac{15 - 10}{10.5 - 7.3} = \frac{5}{3.2} = 1.6$ m/s

4) $\frac{20 - 15}{14 - 10.5} = \frac{5}{3.5} = 1.4$ m/s

Sample Calculations Using Distance and Lap Time

1)	$\frac{5 - 0}{3.8} = \frac{5}{3.8} = 1.3$ m/s
2)	$\frac{10 - 5}{3.5} = \frac{5}{3.5} = 1.4$ m/s
3)	$\frac{15 - 10}{3.2} = \frac{5}{3.2} = 1.6$ m/s
4)	$\frac{20 - 15}{3.5} = \frac{5}{3.5} = 1.4$ m/s

Sample Distance-Time Graph



Did your object move at a constant velocity or an irregular velocity? How do you know? *Encourage your child to look at both her graph and her calculations as she answers this question. In the sample graph above, this object looks like it moved at a constant velocity because the slope of the line is fairly straight. However, when you look at the velocity calculations in the answer key above, you can see that the object's velocity was actually irregular.*

Activity 3: Calculating Acceleration

The calculations in this activity might be challenging for your child because the numbers may be quite small. If she has difficulty, you may want to do them with her. Help her understand that the average accelerations she is calculating tell her how much the object's velocity has changed between each time marker. When she sees the velocities on the graph she

creates, this connection will hopefully become more clear. How does the velocity-time graph reflect what she observed about the motion of her object when she did her investigation yesterday?

As for the previous activity, below are sample calculations and a sample graph for this activity. Your child's answers will be different. In assessing your child's activity, make sure that she is using the correct formula and units of measurement for time (seconds), velocity (meters/second), and acceleration (meters/second squared).

Answer Key:

Sample Data Chart

	Elapsed Time (s)	Lap Time (s)	Velocity (m/s)
Start	0	0	0
Marker 1	3.8	3.8	1.3
Marker 2	7.3	3.5	1.4
Marker 3	10.5	3.2	1.6
Finish	14	3.5	1.4

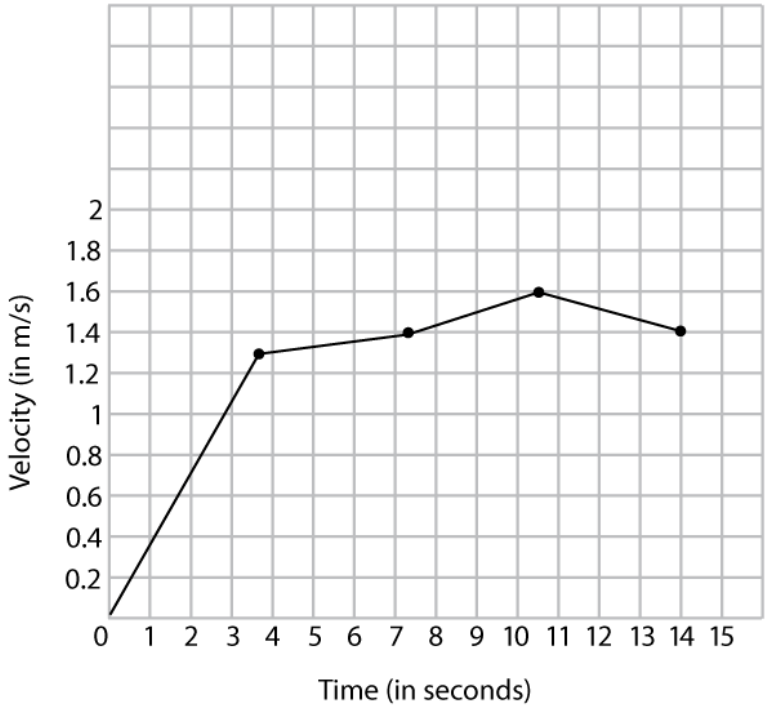
Sample Calculations Using Distance and Elapsed Time

1)	$\frac{1.3 - 0}{3.8 - 0} = \frac{1.3}{3.8} = 0.34\ m/s^2$
2)	$\frac{1.4 - 1.3}{7.3 - 3.8} = \frac{0.1}{3.5} = 0.03\ m/s^2$
3)	$\frac{1.6 - 1.4}{10.5 - 7.3} = \frac{0.2}{3.2} = 0.06\ m/s^2$
4)	$\frac{1.4 - 1.6}{14 - 10.5} = \frac{-0.2}{3.5} = -0.06\ m/s^2$

Sample Calculations Using Distance and Lap Time

1)	$\frac{1.3 - 0}{3.8} = \frac{1.3}{3.8} = 0.34\ m/s^2$
2)	$\frac{1.4 - 1.3}{3.5} = \frac{0.1}{3.5} = 0.03\ m/s^2$
3)	$\frac{1.6 - 1.4}{3.2} = \frac{0.2}{3.2} = 0.06\ m/s^2$
4)	$\frac{1.4 - 1.6}{3.5} = \frac{-0.2}{3.5} = -0.06\ m/s^2$

Sample Velocity-Time Graph



Did your object move at a constant acceleration or an irregular acceleration? How do you know? *Encourage your child to look at both her graph and her calculations as she answers this question. In the sample graph above, this object clearly moved at an irregular acceleration. Its velocity increased quickly in the beginning, increased more slowly between markers 1 and 3, and decreased slightly as it crossed the finish line. You can see the rate of change of this object's velocity when you look at the average acceleration calculations.*

Wrapping Up

Questions to Discuss

- Give an example of the presence of the following occurring in your investigation of a moving object: an unbalanced force, a balanced force, and inertia. (Unbalanced force: any object moving that was once stationary or a moving object becoming stationary; balanced force: a stationary object, an object with consistent velocity; inertia: an object at rest or in motion in a straight line at the same speed.)
- How does the motion of an object produce a force that has direction? (When the force is applied, the object moves in the direction that the force was applied. Gravity pulls an object down; a ball that is thrown moves in the direction that it was thrown.)

Things to Review

- Force has direction.
- The velocity of an object is the rate of change of its position.
- The acceleration of an object is the rate of change of its velocity over time.