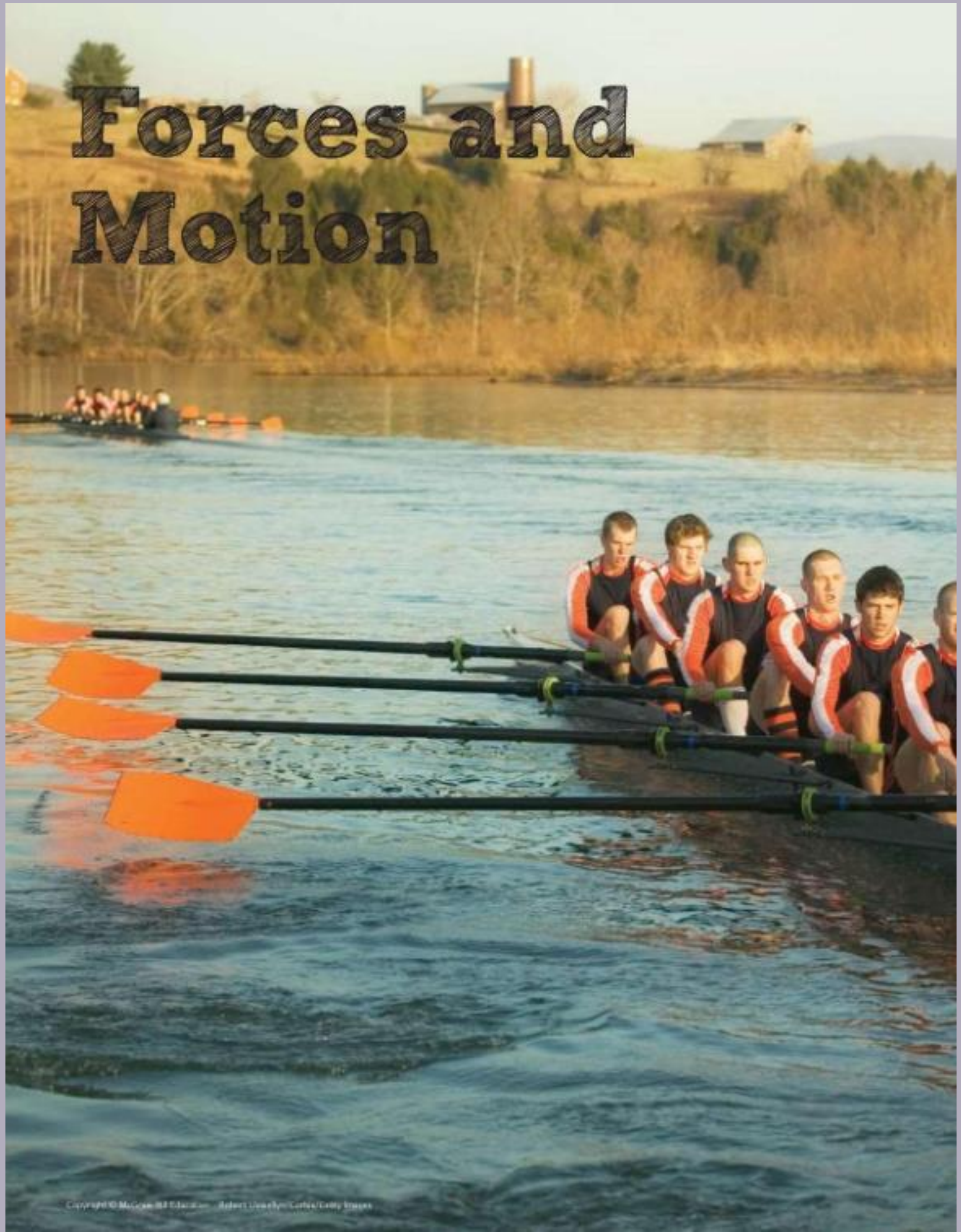
MODULE 1



LESSON 1

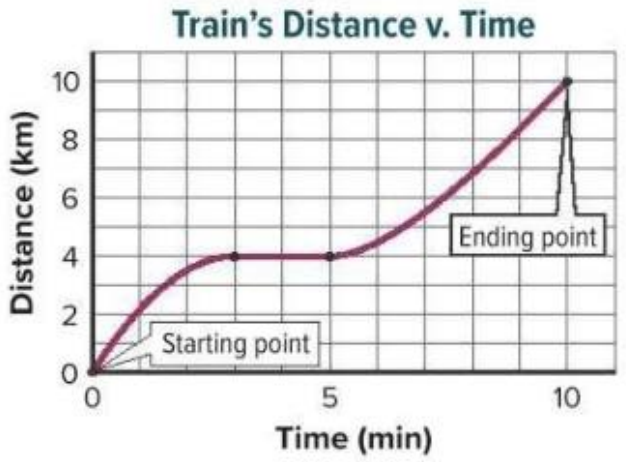
Lesson Objective

Students will explore how to **describe the position and motion of an object.** They will **analyze data** including graphs to help **construct and present arguments** about the **changes over time** in the motions of objects.

Vocabulary

Term	Definition
reference point	the starting point you choose to describe the location, or position, of an object.
position	an object's distance and direction from a reference point.
motion	the process of changing position.
displacement	the difference between the initial, or starting, position and the final position.
speed	a measure of the distance an object travels in a given amount of time.
velocity	the speed and the direction of a moving object.
vector	a quantity that has both magnitude and direction.

Train Ride



The graph shows a train traveling between two stations. Circle what you think is the best interpretation of the graph.

A. The train sped up during the first 3 minutes, slowed down for several minutes, then sped up again.

B. The train went uphill, traveled on flat ground, then went uphill again.

C. The train sped up for 3 minutes, traveled at a steady speed for 2 minutes, then sped up again.

D. The train sped up then slowed down during the first 3 minutes, stopped for two minutes, then sped up again.

E. The train traveled at a steady speed uphill for most of the way except for in the middle when it stopped for 2 minutes.

ENCOUNTER
THE PHENOMENON

How can you describe the position and motion of the train outside the window?

Imagine you are sitting on a train like the one shown. Using the photo for visual clues, in your Science Notebook describe the position and motion of the train outside the window.

Now describe the position and motion of the train you are sitting on.

ENCOUNTER THE PHENOMENON

How can you describe the position and motion of the train outside the window?

Imagine you are sitting on a train. Using the photo on the previous page for visual clues, describe the position and motion of the train outside the window.

Answers will vary. The photo is purposely ambiguous. Students may argue that the other train isn't moving. They may also argue that the other train is moving. They may argue that their train is moving faster than the other train. They may argue the other train is moving from left to right.

Now describe the position and motion of the train you are sitting on.

Answers may vary. Students may notice that the ground outside the train appears blurry, which indicates their train is in motion. Students may argue that since their train is in motion, their train is passing the other train.

Students' answers will vary. Students' claims may include that the position and motion of the train can be described by describing how fast it moves and which direction it is moving.

EVIDENCE

Scientific evidence is information that supports or contradicts a claim. This information can come from a variety of sources. Research, experimentation, or data interpretation are common sources of scientific evidence. In science, it is important to have multiple pieces of evidence to support your claim. Encourage students to return to their claim and add evidence at multiple points in the lesson. If students cannot find evidence to support their claim, they will need to continue to investigate.

A. Answers may vary. Sample Answer: Position can be described using a reference point, a reference direction, and the distance from the reference point in the reference direction. In our investigations, we found that the description of an object's position and direction on a ruler depended on the reference point chosen.

B. Answers may vary. Sample Answer: Motion is the process of changing position. It involves both direction and speed. The wind-up toys moved forward, so their reference direction was the same. We described their motion by how their position and the distance they traveled in a given time changed.

C. Answers may vary. Sample Answer: Changes in motion occur over time. Speed is a measure of the distance an object travels in a given amount of time. Velocity is the speed and direction of a moving object. We had to describe changes in position over time of the wind-up toys, which let us describe how their motion changed. Arrows let us model the changes in speed and direction.

D. Answers may vary. Sample Answer: A graph can show how distance and time are related for an object. As we saw when we plotted data for a train, the slope of a distance-time graph shows how fast the object travels. A steeper line indicates a greater speed.

REVISED CLAIM

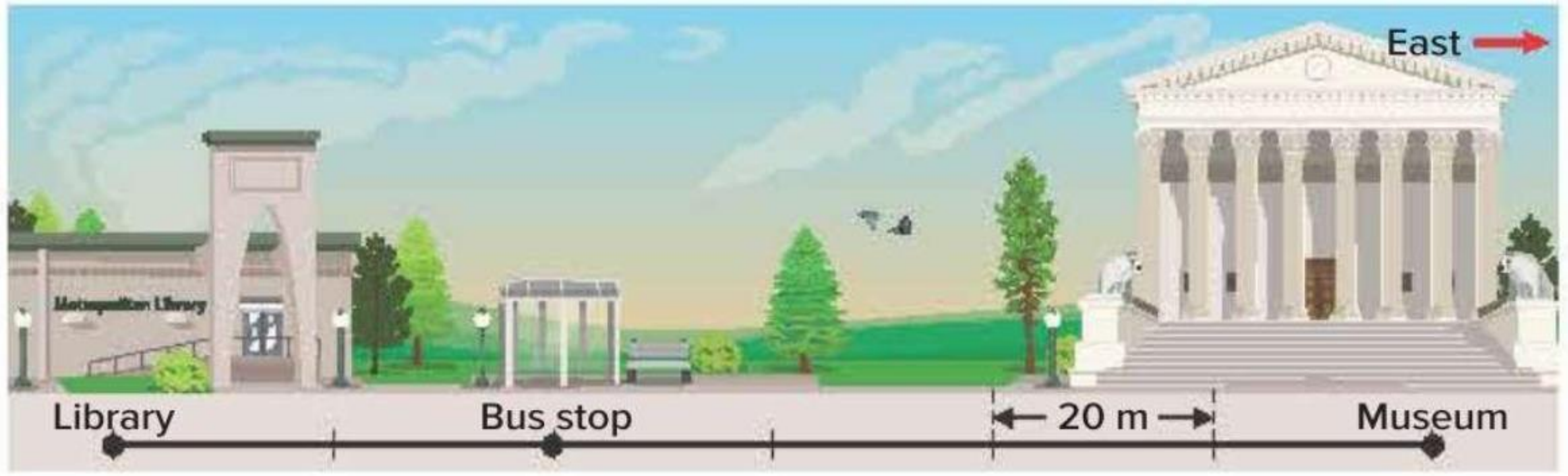
Have students review the evidence they collected. Students should have recorded evidence that supports their claim. If students found evidence that contradicts their claim, their claim is likely incorrect. Encourage students to use the evidence they recorded to revise their claim.

Students' answers will vary. Sample answer: The position and motion of the train can be described by an arbitrarily chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared.

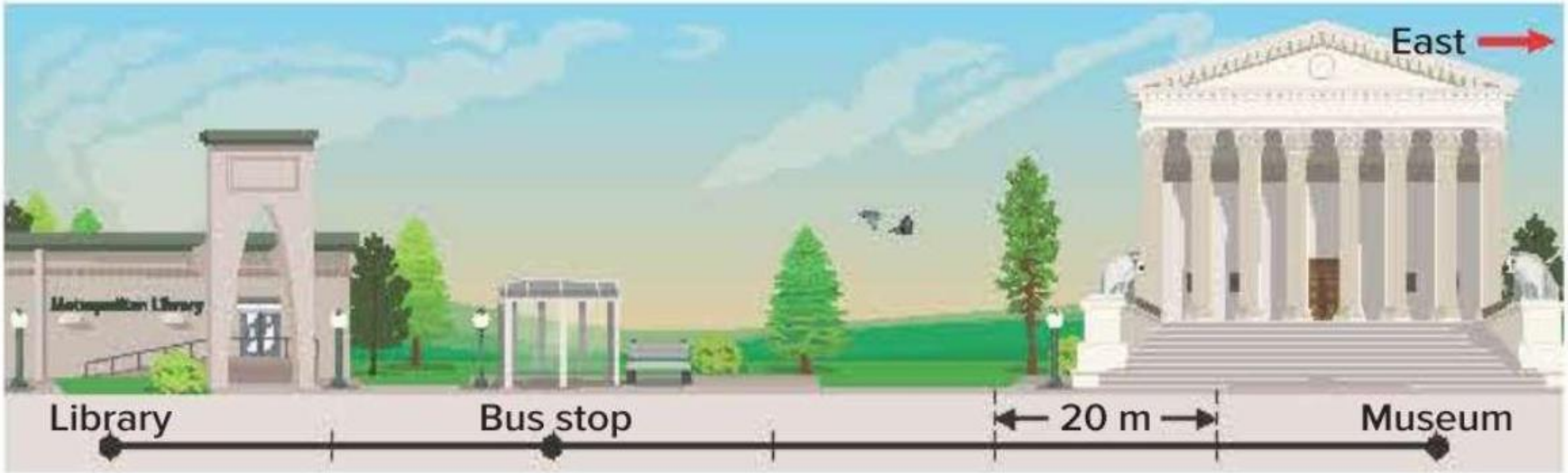
Describing Position To describe position you must state your location relative to a certain point. A **reference point** is the starting point you choose to describe the location, or position, of an object. The chosen point is arbitrary, which means that you pick the point based on your preference. The reference points from the paragraph on the previous page are your friend, your school, the center of town, and the Sun.

A description of your location also includes your distance and direction from the reference point. Describing your location in this way defines your position. A **position** is an object's distance and direction from a reference point. A complete description of your position includes a distance, a direction, and a reference point. Let's explore the relationships between those three things.

The Reference Direction

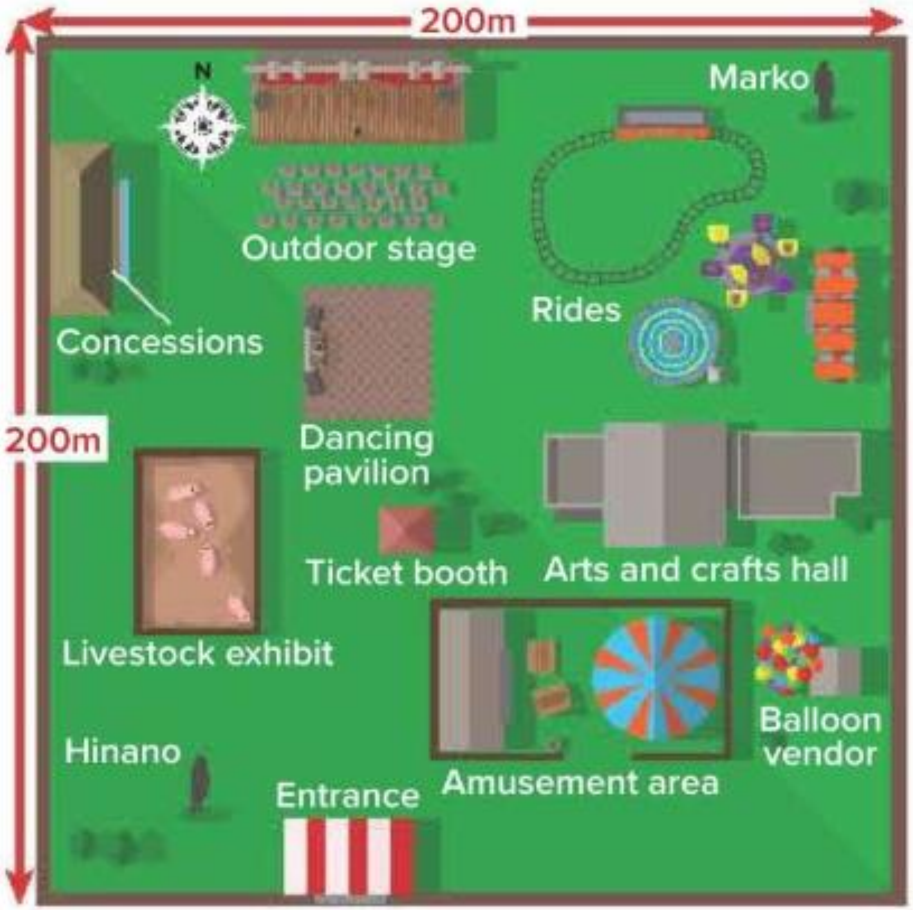


The Reference Direction When you describe an object's position, you compare its location to a reference direction. The reference direction is the positive (+) direction. In the first part of the Investigation *Start From Here,* any number greater than 50 cm was in the positive direction. The opposite direction is the negative (−) direction. As with the reference positon, reference direction is arbitrary. You decide which direction is positive and which is negative. Suppose you specify east as the reference direction in the figure below. You could say the museum's entrance is +80 m from the bus stop. The library's entrance is −40 m from the bus stop.



See You Soon

Hinano and Marko agree to meet at the state fair. Hinano arrives at the entrance. Marko gives Hinano two-part instructions explaining how to find him. His instructions use three reference points (including her starting point), two directions, and two approximate distances. The instructions describe the shortest walking distance between them. Study the diagram and then answer the questions.



1. What instructions do you think Marko gave Hinano?

2. What is an alternative route for Hinano to find Marko?

1. What instructions do you think Marko gave Hinano?

From the entrance, walk about 100 m north to the west side of the ticket booth. From that new reference point, walk about 125 m northeast past the southeast corner of the train ride.

2. What is an alternative route for Hinano to find Marko?

From the entrance, walk straight east about 130 m. When you reach the balloon vendor, turn north. Walk straight north about 150 m.

Describing Position in Two Dimensions

To find a position in 2D:

1. **Choose a reference point.**
2. **Specify reference directions.**
3. **Determine the distance along each reference direction.**

Describing Position in Two Dimensions When Marko told Hinano his location using two directions, he was using two dimensions. Marko used meters in his description. Meters are the base unit of length per the International System of Units (SI). Like the reference point and the reference direction, the units used are arbitrary. Scientists use SI units to eliminate confusion of multiple measurement systems.

Position can also be described by using a cardinal direction like *north*, *south*, *east*, or *west* as a reference direction. Other times the reference direction can be as simple as *right or forward*. To describe the position of a window on a building, you might choose *left* and *up* as reference directions.

Finding a position in two dimensions is similar to finding a position in one dimension. First, choose a reference point. To locate your classmate's home on the map below, you could use your home as a reference point. Next, specify reference directions—south and east. Then, determine the distance along each reference direction. In the image below, your classmate's house is one block south and one block east of your house. In order to communicate the directions to a friend, you have to share the position, direction, and units that you are using.

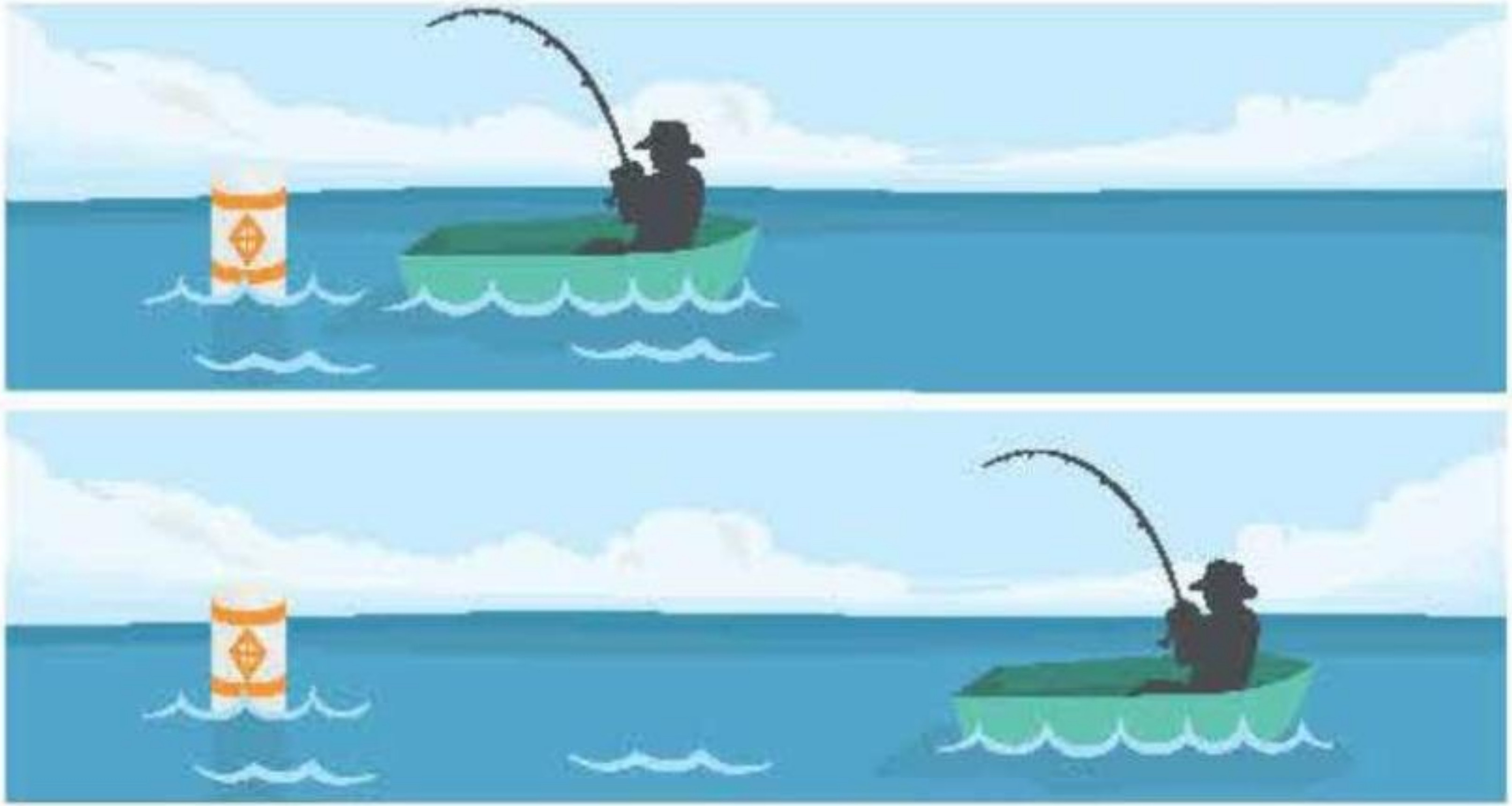
To find a position in 2D:

1. **Choose a reference point.**
2. **Specify reference directions.**
3. **Determine the distance along each reference direction.**

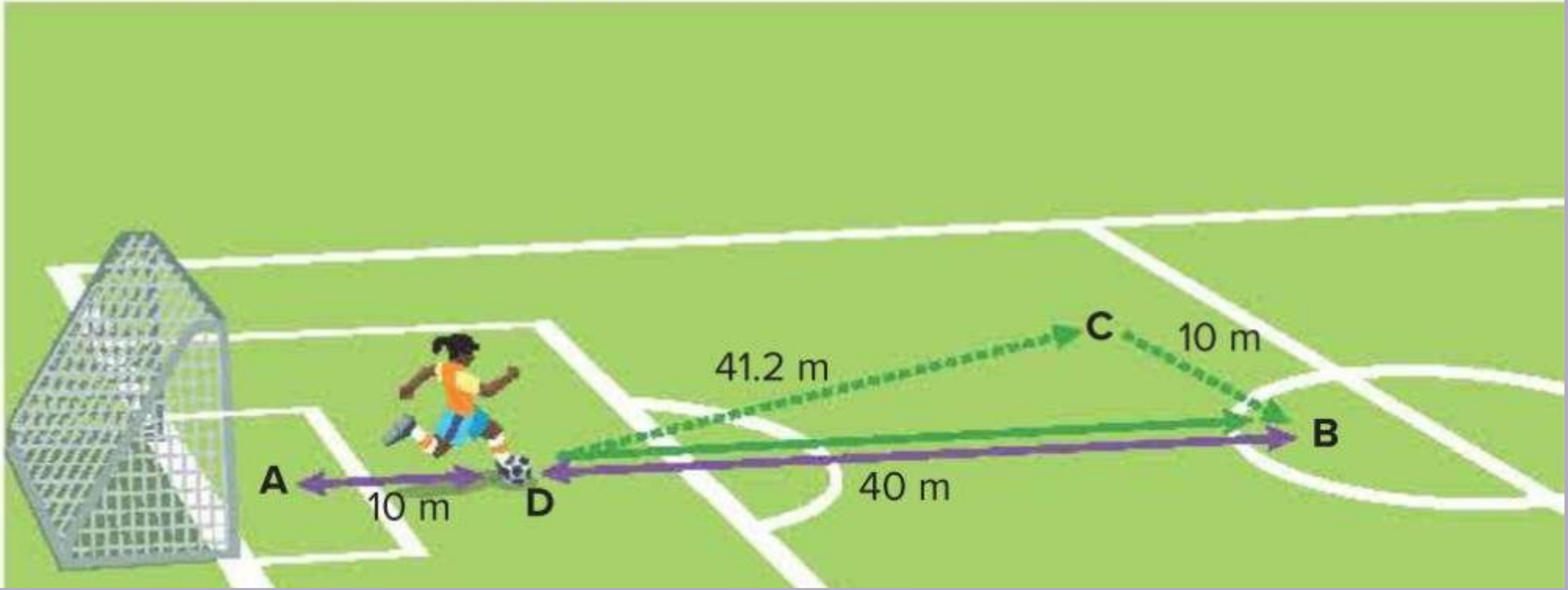
What is motion?

Motion When you described the motion of the object in the Lab *Watch It Go*, you should have included how the object's position changed. You can tell the object moved because its position changed relative to the reference point. **Motion** is the process of changing position.

Observing Motion Look below at the figure of the man fishing. Is the man in motion between the top part of the figure and the bottom part? Suppose the fishing pole is the reference point. Because the positions of the man and the pole do not change relative to each other, the man does not move relative to the pole. Now suppose the buoy is the reference point. Because the man's distance from the buoy changes, he is in motion relative to the buoy. All motion is relative to a certain other point in space.



Motion Using Reference Points Suppose you are watching a soccer game like the one in the figure below. The position of a player depends on a reference. If the reference point is the goal, or point A, the player's position is 10 m in front of the goal. If the reference point is center field, point B, the position of the player is 40 m toward the goal. Notice that the actual location of the player has not changed. Only the description of the position changed because the reference point changed.

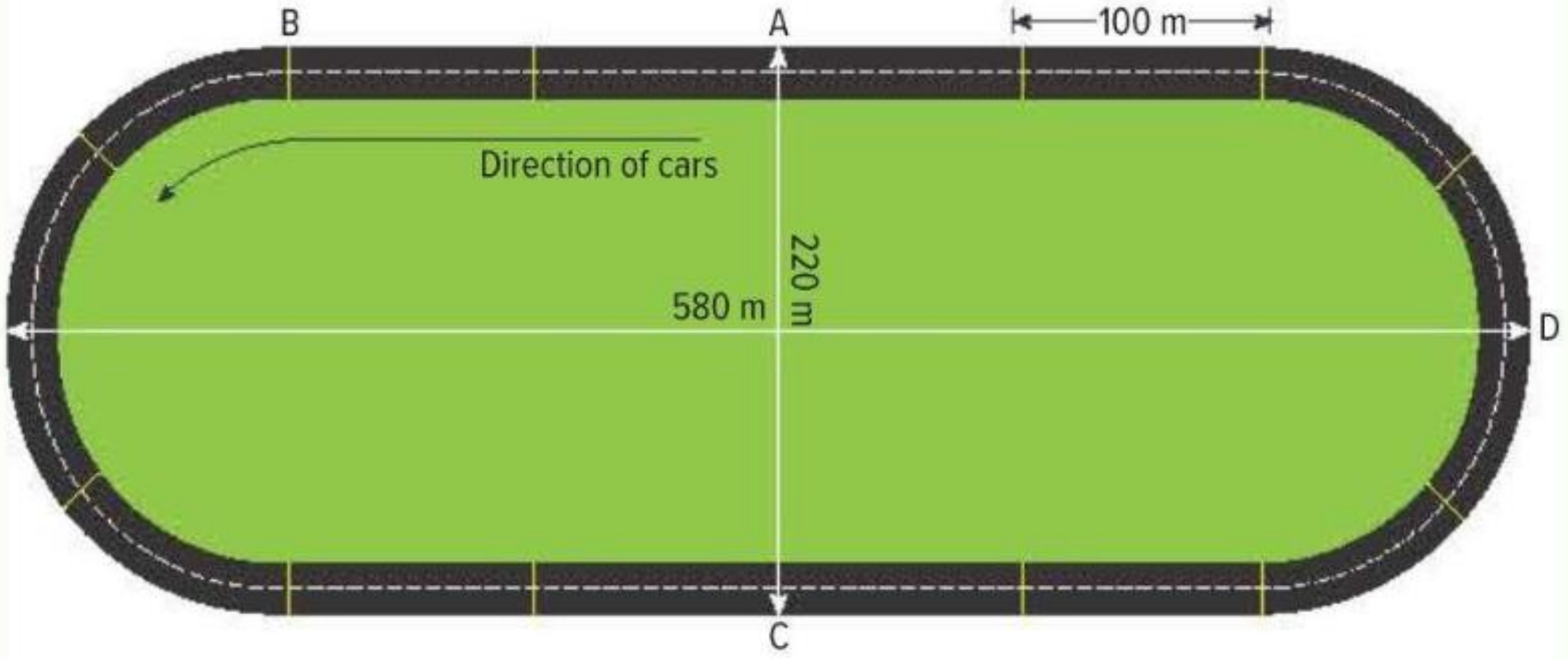


Distance and Displacement During one play in the soccer game on the previous page, the player runs 41.2 m from position D to position C. Then she runs 10 m to position B. Her path is shown by the green dotted lines. The total distance the player travels is 41.2 m + 10 m = 51.2 m.

The solid purple arrow in the figure shows the player's displacement. **Displacement** is the difference between the initial, or starting, position and the final position. The player starts at point D and finishes at point B. Her displacement is 40 m in front of her initial position. Displacement is the shortest distance between where the player started and the player's final position. An object's displacement and the distance it travels are not always equal. If the player runs directly from point D to point A, then both the player's distance and displacement are the same quantity—10 m. If the player's final position is the same as her starting position, her displacement is 0 m.

THREE-DIMENSIONAL THINKING

Use the race track **model** below to determine the distance traveled and the displacement of a car from point A to when it reached point D on the first lap.



THREE-DIMENSIONAL THINKING

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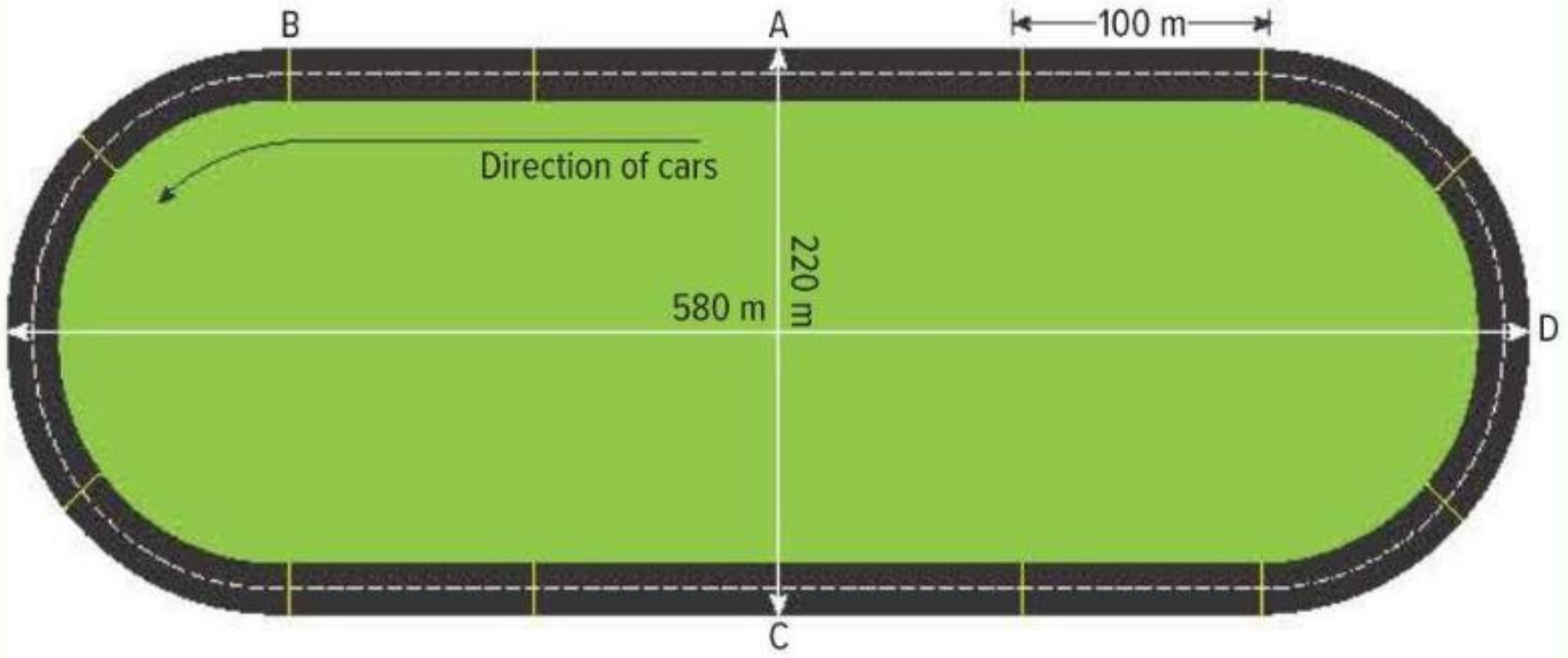

The distance the car traveled is 1,200 m. The displacement is 310 m toward the southeast. This is calculated using the Pythagorean theorum using 110 m and 290 m as the sides of the right angle and solving for the hypotenuse.

What do you measure to determine motion?

Changes Over Time In the Lab *Be the Fastest*, did all of the toys move at the same rate? Did some move slowly and others move quickly? Describing how fast something moves is the same as determining its speed. **Speed** is a measure of the distance an object travels in a given amount of time.

Constant and Changing Speed Speed can be constant or changing. Look at the figure below. The stopwatches above the girl show her motion every second for 6 seconds. In the first 4 seconds, the girl moves with constant, or unchanging, speed because she travels the same distance during each second. When the girl starts running, the distance she travels each second gets larger and larger. The girl's speed changes because she is moving a different distance each second.

Average Speed The speed of most moving objects is not constant, which is why the speedometer in a car is always changing slightly. Therefore, when you describe your speed over an entire trip to someone, you are describing average speed. Average speed is equal to the total distance traveled divided by the total time. Average speed can be modeled mathematically using the equation below.

Average Speed Equation

$$\text{average speed (in m/s)} = \frac{\text{total distance (in m)}}{\text{total time (in s)}}$$

$$\bar{v} = \frac{d}{t}$$

The symbol $\bar{v}$ represents the term "average velocity." You will read more about velocity, and how it relates to speed, later in the lesson. At this point $\bar{v}$ is simply used as the symbol for "average speed." Imagine the girl above traveled 25 m from second 1 to second 7 on the stopwatch. Therefore, her average speed is 25 m/6.0 s or 4.2 m/s.

MATH Connection The motion of a person or object can be explained by examining how the position changes over time. Practice using the mathematical model, the average speed equation.

1. A truck driver makes a trip that covers 2,380 km in 28 hours. What is the driver's average speed in km/h?

2. What is the average speed of a soccer ball that travels 34 m in 2.0 s?

3. How long would it take a bus traveling at 52 km/h to travel 130 km?

MATH Connection The motion of a person or object can be explained by examining how the position changes over time. Practice using the mathematical model, the average speed equation.

1. A truck driver makes a trip that covers 2,380 km in 28 hours. What is the driver's average speed in km/h?

85 km/h

2. What is the average speed of a soccer ball that travels 34 m in 2.0 s?

17 m/s

3. How long would it take a bus traveling at 52 km/h to travel 130 km?

2.5 h

THREE-DIMENSIONAL THINKING

Isaiah leaves one city at noon. He has to be at another city 186 km away at 3:00 PM. The speed limit the entire way is 65 km/h. Can he arrive at the second city on time? Explain your reasoning using **mathematical evidence.**

THREE-DIMENSIONAL THINKING

Isaiah leaves one city at noon. He has to be at another city 186 km away at 3:00 PM. The speed limit the entire way is 65 km/h. Can he arrive at the second city on time? Explain your reasoning using **mathematical evidence.**

Yes. To arrive on time, his average speed must be at least 186 km divided by 3 h or 62 km/h, which is lower than the speed limit.

Point the Way

Have you ever been asked for directions and pointed to where the person needed to go? You were indicating direction. Similar to pointing, motion can be represented with arrows. An arrow can point left, right, up, or down indicating direction. An arrow's length can vary to indicate speed. A longer arrow would represent a faster speed.

1. An airplane flew from San Francisco to Washington, D.C. Approximately halfway through the flight, the plane had traveled 2,000 km in 2.5 hours. What was the speed during this period?

2. Another airplane is flying in the opposite direction. It covers the same distance in exactly 2 hours. What was its speed and direction during this period?

3. Draw arrows representing the speed and direction of the two planes. Label each arrow with the speed and direction of flight. Use a left-facing arrow for *west* and a right-facing arrow for *east*.

First plane	Second plane

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1. An airplane flew from San Francisco to Washington, D.C. Approximately halfway through the flight, the plane had traveled 2,000 km in 2.5 hours. What was the speed during this period?

800 km/h

2. Another airplane is flying in the opposite direction. It covers the same distance in exactly 2 hours. What was its speed and direction during this period?

1,000 km/h to the west

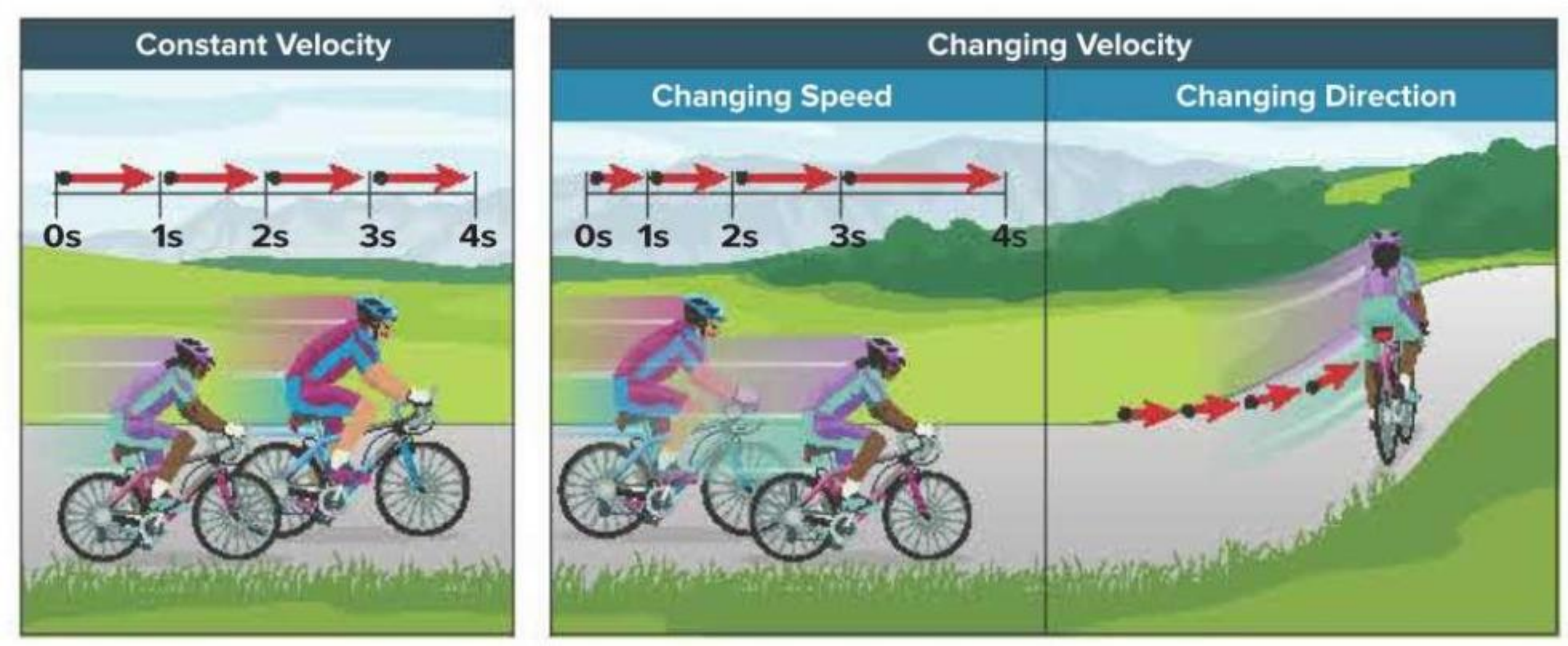
3. Draw arrows representing the speed and direction of the two planes. Label each arrow with the speed and direction of flight. Use a left-facing arrow for *west* and a right-facing arrow for *east*.

First plane	Second plane
→	←
800 km/h to the east	1,000 km/h to the west

Speed and Direction In the Investigation *Point the Way,* you identified the speed and direction of two planes. Both speed and direction are part of motion. **Velocity** is the speed and direction of a moving object. Velocity is referred to as a vector. A **vector** is a quantity that has both magnitude and direction. To share the direction and magnitude, arrows are used to represent vectors. The plane traveling to Washington, D.C. was represented with a smaller vector than the plane flying into San Francisco.

Constant and Changing Velocity Like speed, velocity can either be constant or changing. When velocity is constant, the object is moving at a constant speed and its direction does not change. If either the speed or the direction of the object changes, the velocity will change.

Look at the figure below. It is a motion diagram. A motion diagram is a series of images showing the positions of moving objects at equal time intervals. A motion diagram can be simplified by replacing the objects with dots. Velocity is shown by adding arrows to the dots. Each dot represents a time frame such as 1 s. Notice how from one position to the next, the arrows showing the velocity of the cyclists change length. The arrows can also show a change in direction. The changes in the arrows mean that the velocity is constantly changing.



Constant Velocity
0s
1s
2s
3s
4s
Changing Velocity
Changing Speed
0s
1s
2s
3s
4s
Changing Direction

How can a graph help you understand an object's motion?

INVESTIGATION

Plot It

1. Plot the distance and time data for distance the train traveled on the grid below. Plot the distance on the vertical axis and time on the horizontal axis. Label the axes and add a title to your plot.

Distance Traveled by Train	
Time (h)	**Distance (km)**
0	0
1	110
2	220
3	330
4	400
5	500

3. What does the graph tell you about the distance traveled by the train?

4. What does the graph tell you about the amount of time that has passed?

5. What do you think happened to the speed of the train during each hour represented on the graph?

6. **MATH Connection** Choose two points on your graph. Find the time difference of the points. Next, find the distance difference of the points. Then, divide the difference in the distance by the difference in time. What is your answer? What mathematical value did you calculate?

Students should plot their data on the grid. They should add labels, a title, and a key to the plot.

3. What does the graph tell you about the distance traveled by the train?

Sample answer: The train traveled a total distance of 500 km. The distance traveled in the fourth and fifth hours was less than the distance traveled in each of the first 3 hours.

4. What does the graph tell you about the amount of time that has passed?

The train traveled for a total of 5 hours.

5. What do you think happened to the speed of the train during each hour represented on the graph?

Sample answer: The train's speed remained the same for the first 3 hours. Between the third and fourth hours, the speed decreased by 40 km/h. Between the fourth and fifth hours, the speed increased by 30 km/h to 100 km/h.

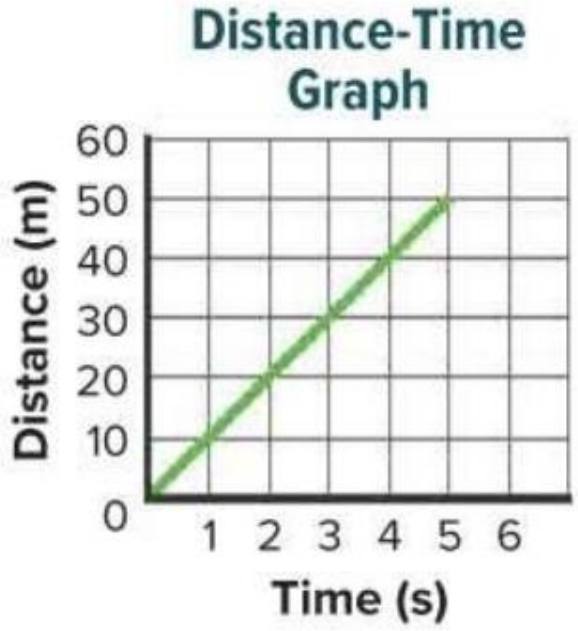
6. **MATH Connection** Choose two points on your graph. Find the time difference of the points. Next, find the distance difference of the points. Then, divide the difference in the distance by the difference in time. What is your answer? What mathematical value did you calculate?

Answers will vary based on the points chosen. Sample answer: Points chosen (1, 110) and (3, 330). 220 km/2 h = 110 km/h. The slope of the line has been calculated, which is the speed of the train.

Distance-Time Graphs The plot you made in the Investigation *Plot It* is a distance-time graph. This type of graph shows how an object's position changes during each time interval. A distance-time graph does not show you the actual path the object took.

Did you notice that the line through the points in the investigation wasn't completely straight? When an object is moving at a constant speed, the line will be straight. The steeper the line, the greater the slope, which means the greater the speed of the object.

If the slope of the line changes, this means the speed of the object has changed. Even if the speed has changed, the average speed can still be calculated.



ADDITIONAL RESOURCE

PhET Interactive Simulation: The Moving Man

https://phet.colorado.edu/sims/cheerpj/moving-man/latest/moving-man.html?simulation=moving-man

Simulation: Velocity and Acceleration

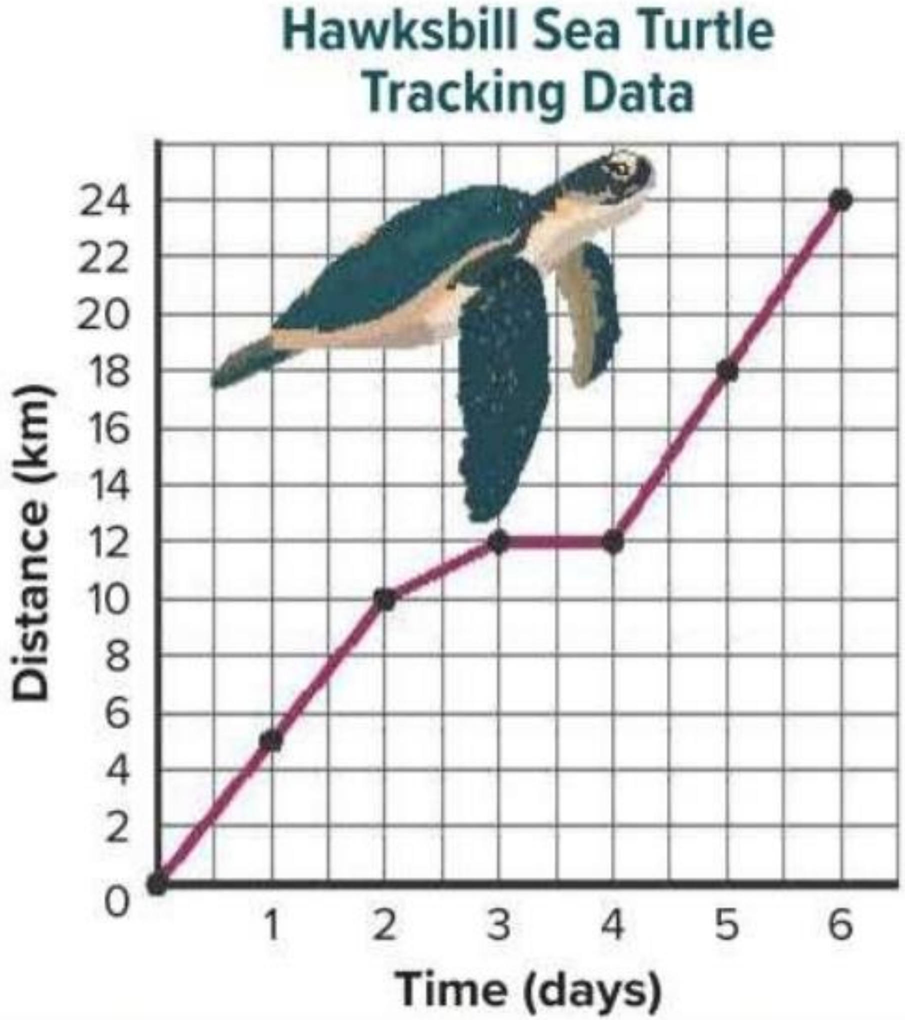
Description: Discover, engage, and explore scientific concepts with research-based simulations.

Tags: Web

https://nt7-mhe-complex-assets.mheducation.com/nt7-mhe-complex-assets/Upload-20201207/Velocity_English_with_ReadSpeaker/index.html

THREE-DIMENSIONAL THINKING

Analyze the data on the plot below. Determine the speed of the hawksbill sea turtle during each interval listed below.



Day 0 to day 2: ____________________

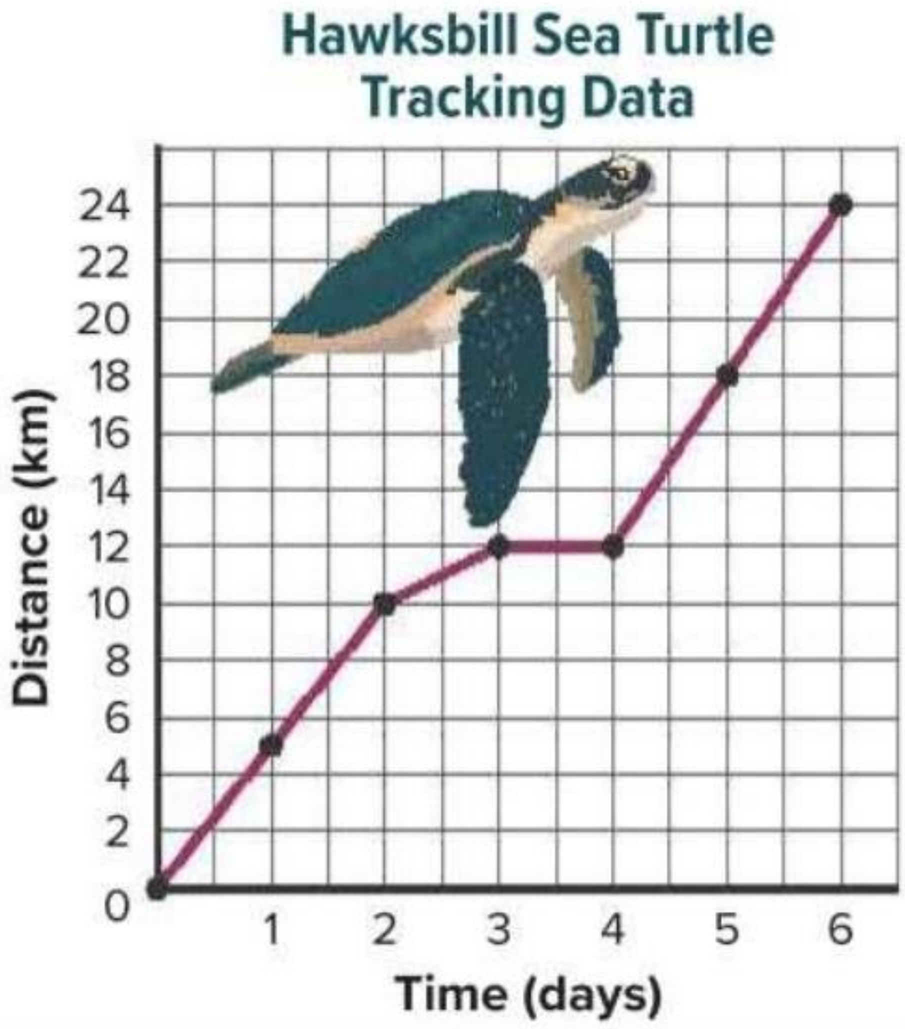
Day 2 to day 3: ____________________

Day 3 to day 4: ____________________

Day 4 to day 6: ____________________

THREE-DIMENSIONAL THINKING

Analyze the data on the plot below. Determine the speed of the hawksbill sea turtle during each interval listed below.



Day 0 to day 2: 5 km/day

Day 2 to day 3: 2 km/day

Day 3 to day 4: 0 km/day

Day 4 to day 6: 6 km/day

LESSON 1

Review

Summarize It!

1. **Construct and Present Arguments** A distance-time graph shows the motion of two bicycle riders. Each rider's motion is represented on the graph by a diagonal line sloping upward from left to right. The graph shows that they traveled the same distance. However, the line representing the motion of Rider #1 slopes upward more steeply than the line representing the motion of Rider #2. Sketch a graphical model of the motions of the riders. Develop an argument on which rider arrived at his or her destination first. How do you know? Use evidence to add validity to your argument.

The comparative slopes of the lines on the graph indicate that the speed of Rider #1 was greater than the speed of Rider #2. Therefore, Rider #1 covered the same distance as Rider #2 in less time and arrived first.

Three-Dimensional Thinking

Analyze the data table below. Use the table to answer questions 2 and 3.

Green Sea Turtle's Distance and Time Data

Time (days)	Distance (km)
0	0
1	16
2	32
3	48
4	64
5	80
6	96

2. The data in the table above shows how far a sea turtle travels over several days. What would the line on a plot of this data look like?

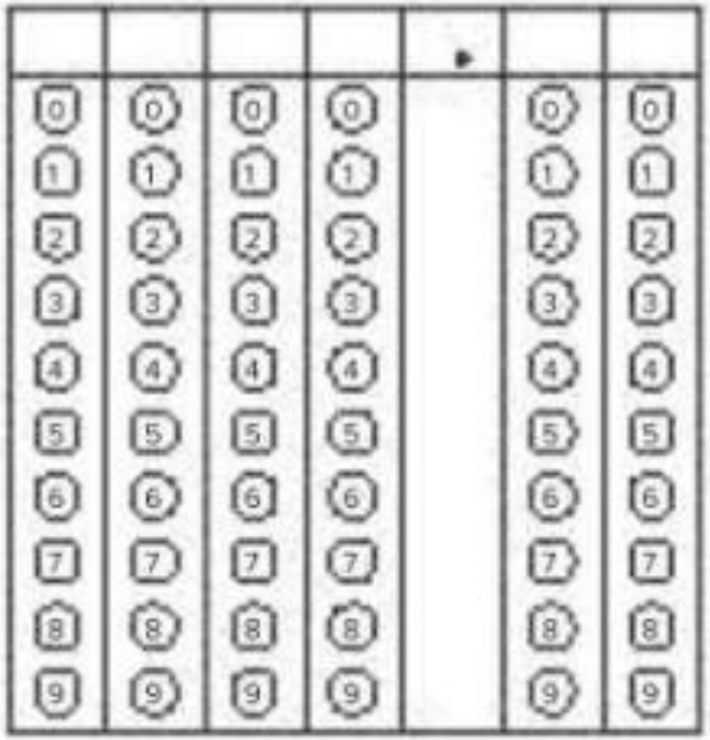
A The line would curve upward and to the right.

B The line would go up and down.

C The line would point straight upward to the right.

D The line would point upward then downward.

3. If the turtle continued the motion recorded in the data table above, what would his distance be at ten days?



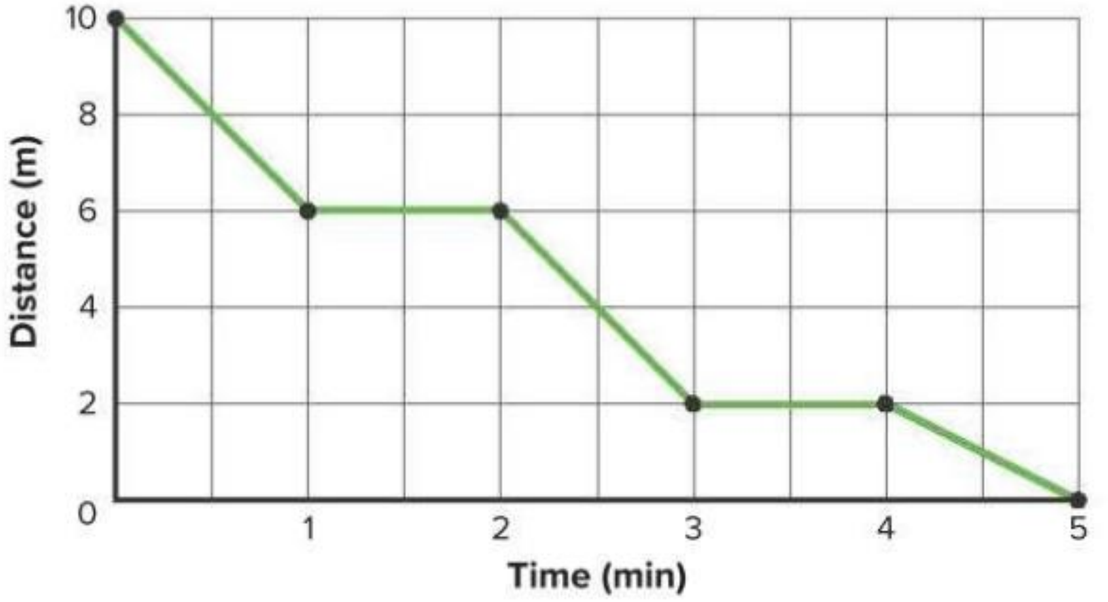
Three-Dimensional Thinking

2. **C—Correct.** A is incorrect because the line is straight, representing a constant speed. B and D are incorrect because the distance increases each day, so the graph never goes down.

3. **160—Correct.** The turtle travels 16 km each day, so in 10 days it would travel a total of 160 km.

Real-World Connection

4. **Interpret Data** The plot below shows the motion of an elevator. Explain its motion.



The elevator went down 4 m at a constant speed for 1 min. It then stopped for 1 min. It went down 4 m in 1 min, stopped for 1 min, and went down 2 m in the final minute.

5. **Calculate** A driver travels 55 km in 1 hour. He then drives at a speed of 35 km/h for 2 hours. Next, he drives 175 km in 3 hours. What was his average speed?

50 km/h