

Learning Experience 1

Teacher Guide

What Is This Thing Called “Physics”? (and What Use Is It Anyway?)

Overview

This learning experience is designed to introduce students to the idea that the principles of physics are an integral part of everything they do and of the physical world around them. The laws of physics can describe the nature of motion, forces, energy, matter, heat, sound, and light. Understanding these laws allows you to understand why things are the way they are; for instance, why the sky is blue. It enables you to understand how things happen, such as the fury of tornados and hurricanes, the cracking sound of a baseball bat as it meets the ball, and the lift of a hawk as it catches an upward draft.. It permits you to make predictions about physical phenomena such as where and when a comet might reappear in the sky. Understanding the principles of physics has also enabled the invention of a myriad of devices that have enhanced human life in many areas, for example, health, transportation, technology, scientific exploration, and the activities of daily living.

The principles of physics have been applied to develop devices and gadgets that make life easier. However, every once in a while someone comes along who takes delight in making a seemingly simple task as complicated as possible. Such a character was Rube Goldberg, an inventor and cartoonist, who could convert a straightforward task like squeezing an orange into a 15-step operation, using principles of physics such as forces, motion, and energy transformations.

In this learning experience, students are challenged to create their own Rube Goldberg contraption that will carry out a task of their choosing, such as turning on a light bulb. Students then identify the places in their invention where they think the principles of physics apply. At the end of this course, students return to their inventions and redesign them according to a set of criteria based on the principles of physics they having been investigating. This final activity serves as a performance assessment for the course.

The purpose of this learning experience is to have students think about inventions and the kinds of knowledge they need to develop a device or gadget. This discussion serves has a “warm-up” for students, so they can begin thinking about the role of science, particularly physics, in their everyday lives.

Goals for Student Understanding

- Students consider that everyday events can be understood by understanding physics

- Students understand that the principles of physics can be applied to carry out tasks and make things happen.
- Students understand that problems can be solved working in a group by predicting and by experimenting

Student Assessment Outcomes

Students should be able to:

- Develop a plan for building a complex device that accomplishes a simple task.
- Identify examples of motion, force, and energy in their device.
- Communicate their problem-solving strategies and present their solutions to the challenge.
- Critique classmates' designs.

Assumptions of Prior Knowledge and Skills

Students should already know how to work in groups.

Possible Misconceptions or Commonly Held Ideas

None

Assessment Strategies

None

Suggested Class Sessions

5 class sessions (45 minutes each)

Advance Preparation

1. Prepare overhead(s) of one or more Rube Goldberg contraptions to provide examples of his work to students (optional).
2. If you want to demonstrate a Rube Goldberg-like device, obtain the game Mouse Trap and assemble it before the first class session.

Teaching Sequence Preview

Setting the Context

- Students discuss inventions that they have been developed in their lifetime.
- Students discuss what they might need to know to develop an invention.

Experimenting and Investigating

- Students view the video “The Way Things Go” and discuss the kinds of events that occur that “make things go.”
- Students design a “Rube Goldberg” apparatus that will carry out a simple task.
- Students determine the places in their invention where they think the principles of physics apply.

Processing for Meaning

- Students present their device designs and describe where they think the principles of physics apply.
- Students discuss additional information they might need to know about these principles to improve their devices.

Setting the Context

[Student Book page 1]

The purpose of this Setting the Context is to engage student interest in an activity in which they can begin to see that physics can be applied in everyday life and to start identifying some of their ideas about motion, forces, and energy. This activity should also be fun and pique their curiosity about physics.

Begin by having students read the Prologue. Next, have students brainstorm inventions developed during their lifetimes, discuss how each invention has impacted everyday life, and determine what the inventor needed to know to create this invention.

Allow students about 15 minutes to work with their partner, then gather them together for a large group discussion. You may want to keep track of student ideas in a chart that lists the invention, how it has impacted life, and what knowledge the inventor needed. Students' ideas may include cell phones, home computers, the Internet, hybrid cars, plasma TVs, digital audio players (e.g., iPods), and so on. Accept all ideas, even those that may have been around longer than the student knows. Students may not have many ideas about the science principles involved in the devices they list, but they should be able to mention electricity, force involved in motion, heat, waves, energy, and so forth.

After this discussion, inform students that they will be taking on the role of inventor and designing a device to carry out a simple task such as turning on a light bulb. But unlike most inventors, their task involves the opposite of making this task more efficient.

Responses to Brainstorming Questions

1. Make a list of at least 5 items that you feel have been invented in the past 15 years.
2. Discuss how each item has changed the way people do things.
3. Choose one item and think about what kind of science (physics, chemistry, biology, earth science) the inventor might have needed to know to develop this invention and why you think so.

Have students begin by reading Finding the Science in Art . Have them then view the video “The Way Things Go.” This video is actually a work of art as well as science. Swiss artists Peter Fischli and David Weiss use physical and chemical actions and reactions to create a mesmerizing series of chain reactions. The intention of having students watch this video is to have them think about the kinds of events that “make things go” and where motion, forces, and energy might be involved in simple events.

Have students view the video as a class so they can get a big picture of what is happening. Have them view the video at least twice; they may want you to freeze a frame by pausing the video or rewind it to view an event again.

Allow them time to make careful observations and descriptions of the events that are occurring. Encourage students to be very detailed in their descriptions. For example, instead of allowing them to write, “the tire rolled down a ramp and hit a board, which then fell over.....,” they should write, “A tire rolled down a ramp that had a slight incline. It was not clear why the tire started to roll but perhaps someone pushed it. It picked up speed as it went, and when it hit the board, the tire bounced off the board a little and then stopped. The board wobbled and then slammed on the concrete, hitting another board, causing a loud noise.”

ACTIVITY: Finding the Science in Art

Have students present their observations and descriptions. You may want to make a classroom chart that reflects students’ observations and keep track of their descriptions. As students discuss, encourage their thinking about the science principles by asking questions such as:

- What do you think started the bag turning?
- What caused the tire to stop?
- What caused the balloon to inflate?
- What was the effect of the foam as it dripped over the edge of the table?

Encourage students to talk among themselves and ask each other questions about their observations or why they came to certain conclusions.

After the discussion, inform students that they will be using similar principles to design a machine that will carry out a simple task. Many of the same principles they observed in the film can be used in the design of their machine .

Experimenting and Investigating

[Student Book page 2]

ACTIVITY: Doin’ It, the Hard Way

You may want to begin by providing background on Rube Goldberg and showing some of his contraptions on an overhead. Cartoons of his contraptions can be obtained from one of many Web sites about him. Have students consider what kind of approach they think he might have taken—fiddling around or scientific. Students might realize that he did not actually build everything he designed and that many of his designs were extreme (wacky; off-the-wall) and never would have worked. Many of his creations were spoofs of Americans’ love of gadgets, and in his own words were a “symbol of man’s capacity for exerting maximum effort to achieve minimal results.”

Another approach to introducing the challenge is to demonstrate the Mouse Trap game, a Rube Goldberg-like game in which the end result is to capture a mouse in a trap.

Background on Rube Goldberg

Reuben Lucius Goldberg (1883–1970) was a writer, artist, and cartoonist. He began his national career as a sports artist cartoonist for the *New York Evening Mail* in 1907. He quickly developed his own series called *Foolish Questions* in which he asked readers to suggest their own foolish questions for him to draw. The success of this series established Goldberg's national reputation. His next challenge was to create and draw short animated cartoons for the silent picture industry, a daunting challenge because thousands of pictures were needed for just a few minutes of film. The cartoons he may be best remembered for were part of a cartoon series called "The Inventions." Growing up in a time dubbed by some as the Age of Invention in America, Goldberg's cartoons spoofed Americans' obsession with gadgets and the American dream of inventing a new and better way to do almost everything, from catching a mouse to sending a message, thereby becoming an overnight millionaire. In his "Inventions," he incorporated people, animals, flowers, the sun and rain, and other forces of nature as a way of making the most simple task as complicated to complete as possible. This work even earned him a place in Webster's New World Dictionary as an adjective "designating any very complicated invention, machine, scheme, etc., laboriously contrived to perform a seemingly simple operation."

Goldberg's cartoons ran until the 1930s when he decided to devote his efforts to writing short stories and feature articles. In the 1940s, he became well known for powerful political cartoons, one of which won him The Pulitzer Prize for Editorial Cartoons in 1948. At the age of 80, Goldberg decided to try his hand at sculpture, turning out an estimated 300 works in just a few years.

In 1970, the National Museum of History and Technology of the Smithsonian Institution in Washington presented a retrospective of his work entitled "Do It the Hard Way," the only one-man show ever given to a living artist/cartoonist. Rube Goldberg died on December 7, 1970, just two weeks after the opening of the exhibit.

Goldberg's work is still shown in many museums and science centers throughout the country. But his inventiveness is perhaps best remembered in the National Rube Goldberg Machine Contest held annually at Purdue University, an event covered by the national media, thereby bringing his inventions to life for millions of people.

Sources: <http://www.rube-goldberg.com>
<http://www.rube-goldberg.com/html/contest.htm>

Rube Goldberg: The legendary works of America's most honored cartoonist. By Maynard Frank Wolfe. 2000. Simon and Schuster New York

CHALLENGE: How Many Steps Does It Take to Screw in a Light Bulb?

Divide the class into teams of 4 members. Inform them that they will design a machine to accomplish a simple task such as:

- Turn on a lightbulb.
- Drop coins in a cup.
- Turn on a radio.
- Turn off an alarm clock.
- Swat a fly.
- Blow up and break a balloon.
- Make a glass of chocolate milk.
- Extinguish a candle.
- Blow a ping pong ball into a cup.
- Water a plant.

You may want students to choose from a list of tasks provided by you or have them decide on their own task. Have each team decide which task they would like their machine to achieve. Have them check their choice with you to ensure that it can be achieved and is not dangerous.

Suggested Homework

Have students read the introduction and procedure for the activity “Doin’ it the Hard Way.” Each student should create at least one sketch showing how to solve the challenge and be prepared to present it to their group.

During these sessions students design their machines and prepare their presentations. Reaffirm that their design must NOT include live animals, explosives, fire, or noxious chemical reactions.

Facilitating the Challenge

As students discuss their designs, circulate around the room. Listen to ensure that students are on task. As they begin to draw their designs, you may want to help them problem solve by asking questions about the materials they will use (are they appropriate), the connections they are trying to make (are they logical), and so forth. If students need help in remembering how to build a circuit to light a bulb, you may want to demonstrate this to the class.

As part of their challenge, students must identify places in their device where they think the principles of physics apply. This part of the activity will provide you with some insight into students’ prior understandings about concepts such as energy, energy transfer, energy transformation, work, motion, speed, and force. If students seem to be struggling with this part of the challenge, you may want to write these words on the board and tell them to determine where in their machine these words or principles might apply. You may also want to support them by asking questions such as:

- What do you think might make this step happen?
- Do you think this step will work? Why or why not?
- What is required to ensure that a certain step will take place?

Processing for Meaning

[Student Book page 5]

The purpose of this Processing for Meaning is to have students present their designs for their machines, explain clearly how it should work, and identify those places where they think the principles of physics apply.

As students make their presentations, encourage them to identify questions they need to answer to ensure that their machines will function. Questions might include:

- How fast does a ball need to be going to knock over a domino?
- What height does a coin need to drop from to make a mini teeter totter fling an object?
- How can tension be created in a spring?
- How hard does a ball need to bounce off a wall to make another reaction occur?

Encourage students to frame their own questions about their machines, such as, what more they need to know to get them to work, what kinds of materials might work best, what kinds of actions would work, and so on.

After each group has made its presentation, encourage the other students in the class to critique the presenter's design. Possible questions to encourage this discussion are included in the student book.

What to Look for in Student Presentations

- Are students using “scientific” vocabulary? Ask them to explain what certain words mean to them.
- Are their designs realistic? Will they work? At this point, students can be fairly unrealistic since they will be returning to their designs at the end of the module to redesign them, but you may want them to discuss this issue and their thinking behind it.
- Are students asking appropriate questions related to the physics involved?

What to Expect from Students:

- Students should address the challenge.
- Students should make an effort to describe the actions in terms of scientific principles; however, they may not, at this point, have an accurate or in-depth understanding of these principles.
- Students in the class should critique the design, asking questions about the feasibility, pinpointing potential design flaws or places where the machine might not work, and contributing to identifying or clarifying the science involved in each step.

Inform students that in the coming semester, they will be investigating these principles in depth. At the end of the module, they will be challenged to redesign and build a model of the machine that will accomplish their chosen task, not by trial and error but rather by applying the principles that they have learned during the semester.

READING: Phantasmic* Physics

Have students read “Phantasmic Physics.” The purpose of this reading is to give students a preview and warning about the world of physics they are about to enter. Much of the physics relating to forces, motion, and gravity is counterintuitive; that is, the principles and concepts do not necessarily agree with what students have experienced or believe. You may want to spend some time exploring this idea with students. Have them think about questions they may want to ask when confronted with phenomena they may not believe and the kinds of evidence that they would need to change their thinking.

* phantasm – Plato; objective reality as perceived or distorted by the five senses.

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Unit 1

Laws of Motion

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Unit 1: Laws of Motion

Overview

Unit 1 introduces students to the concepts related to motion: speed, how forces interact to cause objects to change speed and direction, and how change in motion relates to force and mass. Students study kinematics and Newton’s three laws as they progress through the unit.

Learning Experience 2 explores speed. Students first examine data from a sprint run by one of the great woman runners, Florence Griffith Joyner. They then use this example to help them plan their own investigation of speed. Students run their own time trials of motion and analyze their speeds, then describe and represent these speeds using words, numbers, and graphs. Students begin to understand that there is a speed associated with an object at every instant in time, formulate a concept of speed as the distance traveled divided by the time spent traveling, and distinguish between constant speed and changing speed.

What causes objects to change speed and direction, and how?—that is the central question of Learning Experience 3. Students examine the set-up for a difficult pool shot shown in the movie “The Color of Money.” They then try to figure out how they can complete that shot. Students practice pool shots, discuss the changes in motion and the forces that are exerted in each shot, and represent forces using simple vector diagrams. From these discussions, students learn that each change in motion requires the exertion of a net unbalanced force, that force is related to an interaction between two objects, and that in each interaction the two objects exert equal forces on each other, although in opposite directions.

In Learning Experience 4, students further explore the relationship between forces and motion by considering whether it is possible to predict changes in motion. Students read about the close finish in the 1998 Boston Marathon women’s wheelchair division, study the story, and identify the variables that affect the speeds of the racers. Students study the effects of the different variables by looking at downhill motion on ramps, learn how to calculate acceleration, and plan and carry out an experiment to see how net force, mass, and acceleration are related. Based on their investigations, students learn that net force, mass, and acceleration are always related in the same way.

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Teacher Guide

A Perfect Race: Measuring Changes in Motion

Overview

The world around us is in constant motion, from the atoms that make up all things to the celestial bodies that move across the night sky; even seemingly inert objects like continents and plants are in motion. In this learning experience, students focus on foot racing as one kind of motion and consider one property of motion that is very familiar to them: speed.

Foot racing is one of the oldest sports. In early times, the major focus of a race was who came in first; that is, who was the fastest over a given distance. Later, people began to keep records of racing times, and finding methods for determining an individual runner's time became important. Breaking records became almost as important as winning the race. Today, determining an individual's times during a race can be extraordinarily precise. Precise data gathered during a race can also be used to improve a runner's performance.

Using the story of a remarkable race run by one of the great woman runners, Florence Griffith Joyner, students analyze data to determine her speeds at various times. By examining this data, students see how motion in a race is measured, and they use this example to help them plan their own investigation of speed. To carry out the investigation, students run their own time trials of motion and analyze their speeds.

By carrying out these analyses of motion, students formulate a concept of speed; distinguish between constant speed and changing speed; learn ways to measure, calculate, analyze, and represent speed in words, numbers, and graphs; and develop awareness that measuring distances and times at shorter intervals gives a more precise calculation of speed. Students are also introduced to a second measurement of motion: direction. The goal of this learning experience is for students to develop a more thorough understanding of speed and its measurement. They are also introduced to the distinction between speed and velocity.

Goals for Student Understanding

- Students know that average speed is quantified as the distance traveled divided by the time spent traveling.
- Students know that there is a speed associated with an object at every instant in time.
- Students know that speed can be constant, increasing, or decreasing.
- Students understand that velocity is a measurement of motion that describes both the speed and direction of the moving object.

Student Assessment Outcomes

Students should be able to:

- Calculate average speed using distance and time data.
- Make distance vs. time and speed vs. time graphs from data.
- Determine whether the speed of an object moving in one direction is constant, increasing, or decreasing using descriptions of motion, graphs of distance vs. time, graphs of speed vs. time, and data tables.
- Construct narratives that offer explanations for an object's speeds.
- Distinguish between speed and velocity.

Assumptions of Prior Knowledge and Skills

Students should already know:

- How to carry out basic mathematical operations involving ratios.
- How graphs can be used to represent data.

Possible Misconceptions or Commonly Held Ideas

Many students confuse the overlapping concepts of position, speed, velocity, and acceleration. In this learning experience, students work on defining, measuring, representing, and understanding speed. Velocity is introduced briefly, and acceleration is introduced in Learning Experience 4.

Assessment Strategies

Students have a number of opportunities in this learning experience to express their initial and developing understanding of concepts related to speed and motion. By taking note of the answers given by students working in cooperative groups or individually you can determine pacing, identify which concepts need or more or less emphasis, and gauge students' understanding of the content at the end of the learning experience. These formative and summative assessment opportunities include:

Opportunities	Page	Information Gathered About
Brainstorming	9	Students' initial ideas of the definition of speed.
Thinking About What You Read	11	Students' ability to interpret text and define and represent speed.
Data Analysis	13	Students' ability to interpret data in charts, calculate speed, calculate time intervals, plot and interpret graphs, and envision speed as a quantity that varies over time.
Procedure questions	16	Students' ability to design investigations, measure data, record data, calculate speed, calculate time intervals, and plot graphs.
Data Analysis	17	Students' ability to compare and analyze data about speed.
Questions for Discussion	18	Students' understanding of the range of concepts presented throughout the learning experience analyze and compare information about speed.

Investigation Report	18	Students' understanding of experimental design and of data recording, manipulation, and representation.
Checking Your Understanding	Appendix B	Students' understanding of the range of concepts presented throughout the learning experience. They can be used in class, for homework, or as a quiz at the end of the learning experience.

You should determine ahead of time which of these assessment opportunities you will evaluate formally (to assign a grade) and which you will evaluate more informally.

Suggested Class Sessions

6–8 class sessions (45 minutes each)

Advance Preparation

1. For Experimenting and Investigating, collect materials for students to use when they measure distance and time (stopwatches, masking tape, metersticks, measuring tapes, motion detectors, etc.). If you are using motion detectors and graphing software for the first time, familiarize yourself with their operation and capabilities.
2. For Experimenting and Investigating, find possible places outside the classroom where student volunteers can sprint or jog 30 meters (or another distance if it is more suitable), such as an outdoor track, the cafeteria, or a long hallway. If it is impossible to meet outside the classroom, create an alternative activity to measure speeds of objects in the classroom, such as pull-back cars.

Teaching Sequence Preview

Setting the Context

- The teacher encourages students to discuss their racing and running experiences.
- Students read and answer questions about the story of a record-breaking race.
- Students analyze data from the race and represent the data in a table and in graphs.

Experimenting and Investigating

- The teacher introduces the challenge of collecting data for monitoring performance and helps keep students focused on the challenge as they proceed through the investigation.
- Students discuss how they might ascertain speeds.
- Students design an investigation to measure the speed of a student runner.
- Students analyze data collected during the race and represent the data in a table and in graphs.
- Students use the data to calculate speeds and create speed vs. time graphs of student runners.

Processing for Meaning

- Students compare and interpret the data and graphs created by all the groups.
- The teacher helps students interpret their findings in terms of the learning experience's understanding goals and assessment outcomes.

Setting the Context

[Student Book page 9]

Purpose

Students read about a sprint and examine data about that sprint. This familiar context helps students think about speed. They describe, calculate, and graphically represent the speeds of the sprinter. Students will:

- Examine data from a 100-meter race run in 1988 by Florence Griffith Joyner (FloJo).
- Determine FloJo's speeds at various times during the race.
- Recognize constant speed and changing speed.
- Graph the data relating to distance and speed in the race.
- Interpret the graphs.
- Begin to understand that the value of speed is usually expressed as an average value over a period of time.

Materials and Preparation

Each student needs:

- 1 copy of Table 2.1 on white paper (use Blackline Master 2-1)
- 2 pieces of graph paper
- 1 calculator

Begin by having students read the Prologue. You may want to have a short class discussion using the Brainstorming Questions provided about students' running experiences before the students read the story about FloJo.

Responses to Brainstorming Questions

1. What kind of running experiences have you had? *e.g., competitive (such as short or long distance; track or cross-country), running for fun, jogging for exercise, late for school, being chased*
2. How did you run in each circumstance? *e.g., very fast, very slowly, slowly at first and then speeding up, alternating fast and slow*
3. Do you run track or have you watched races on TV? How do you measure performance? How do you decide who is the winner of a race or who is the fastest? *Sometimes performance is measured by who wins, sometimes only the final run is measured, and sometimes a run is measured at intervals or checkpoints.*
4. If you wanted to find out your speed, what would you have to know? How would you calculate your speed? *You would need to know distance and time.*
5. If you know your speed in a race or can calculate it, tell the class. Do you think you ran at that speed for the entire race? Why or why not? *If there are students in the class who run track, use their best time to calculate their speed. Students should notice that this calculation is an average speed.*

6. The story you are about to read is titled, “FloJo: The World’s Fastest Woman.” Have you heard of FloJo? What can you tell the class about her? *Since she ran in 1988, it is probable that few students have heard of her.*

STORY: FloJo: The World’s Fastest Woman

Once you’ve discussed the Brainstorming questions, have students read “FloJo: The World’s Fastest Woman” (this can be done as homework before class or read in class silently). This story describes Florence Griffith Joyner’s race during the 1988 Olympic Track & Field Trials in which she set a new women’s world record for the 100-meter sprint.

Have students answer and discuss their responses to the questions in the Thinking About What You Read section.

Teaching Strategies

- You may want to ask students if they have their own questions about the race or FloJo before they tackle the Thinking About What You Read questions.
- You may want to have students consider the questions individually, write their responses on a piece of paper or in their notebooks, and then discuss them with their group or partner. The class can then come together and compare students’ responses.
- As part of the discussion, you should begin to discover students’ prior understanding of speed. Encourage students to derive their own definition of speed and to consider different ways of thinking of and representing speed.

Responses to Thinking About What You Read Questions

1. Prior to the race, FloJo did a warm-up run. How did her speed in the warm-up run differ from her speed in the actual race? *Data are not provided for the warm-up phase, but students’ answers should be able to explain that FloJo’s warm-up had phases of very slow jogging interspersed with fast sprints. In the actual race, her speed varied only a little as she tried to maintain as fast a speed as possible. She was slow at first, then faster, then fastest, and then a little bit slower again.*
2. Develop a visual way to show the speeds of the warm-up run and the speeds of the actual race. *This question can give you insight into students’ prior experiences in representing data. For example, they might think of graphing the two runs. If so, their responses should reflect their understanding of graphing and what can be represented in a graph. Or they may draw a picture that tries to show the differences by comparing the runners at equivalent times.*
3. FloJo said, “It was more or less a perfect race.” What do you think she meant by that comment? *Have students speculate. Encourage them to break down the race into smaller segments. FloJo’s comment might have referred to a quick reaction, getting up to full speed quickly, maintaining maximum speed, good technical execution, etc.*
4. How would you explain what speed is? *Answers may vary; some students may know that speed is the distance divided by the amount of time spent traveling. Others may say how fast someone or something goes, how fast they can cover a certain distance, or other variations.*

You may want to keep track of students' ideas on chart paper and return to these ideas at the end of the learning experience.

5. People most often describe races like FloJo's in terms of the speed of the runner. Why is speed an important measurement of motion? *Speed describes who can be first in a given situation; by knowing speed you can tell how long it takes to travel a certain distance; by knowing speed you can tell how far you can travel in a given time.*
6. Sprints are run on straight tracks, whereas mid-length races are held on oval tracks. How does the direction of the track affect the runner? Why is direction an important measurement of motion? *On an oval track, you would need to lean and use your muscles a little differently to get around the corners. Direction is important because many times you need to travel in a certain direction. Even on a straight track, you have to go in the direction of the track.*

ACTIVITY: FloJo's Stats

Have students read the activity FloJo's Stats and review Table 2.1.

Teaching Strategies

- You may want to review students' understanding of the section and of the data presented in Table 2.1. Questioning the students about these paragraphs will give you some insight into their readiness for independent reading and data interpretation in this course. Also, make sure that students can distinguish a column from a row.
- Remind students that the data shown in Table 2.1 is essential to FloJo and others who are serious about running because it provides a way for them to examine each run and figure out how to improve their performance. It is the kind of analysis FloJo and her coach might have done.

Divide students into groups of four or five students. Have students work with their group to respond to the Data Analysis questions. They will remain in these groups for the Experimenting and Investigating section.

In this activity, students examine data from FloJo's race, figure out how speeds were calculated from that data, analyze FloJo's speeds, make graphs from the data, and analyze the information that is found in the graphs. The analysis of this activity should further students' understanding of the differences among constant speed, speed that changes over time, average speed, and instantaneous speed.

Students will need two or three 45-minute class sessions to complete this activity.

Technical Background

For research and training purposes, big sporting events are often used to obtain data points in small increments (e.g., every 10 meters for a 100-meter sprint). The most common technique used is video analysis. Cameras are mounted perpendicular to the track in the stands. By counting frames (American TV cameras record at 30 frames/second), accurate data points can be obtained at each camera position and split times can be calculated. Another less common technique is to have several timing devices (like the one used at the finish line) along the track.

For FloJo's famous race, no such equipment was in place; thus, no official split times exist. To provide students with the data for their analysis, the data points in the table were generated based on other top sprinters' data and footage from TV coverage of that race to achieve a very realistic representation. The overall time of her race is, of course, accurate.

Teaching Strategies

- You should review the calculations that students need to make to complete Table 2.1. Column 3 requires students to determine the time interval over the 10-meter segment of track. Column 4 requires students to calculate average speed by dividing 10 meters by the time interval. The data in column 5 is an approximation; it assumes that FloJo reaches her average speed of the 10-meter segment of track at the halfway point of the time interval. Students can calculate the halfway point of each 10-meter segment by adding the time duration at the beginning of the 10-meter segment to the time duration at the end of the 10-meter segment and then dividing that number by 2. For example, the answer for the first 10-meter segment would be calculated by adding 0 seconds + 1.80 seconds and dividing by 2 to get 0.90 seconds.
- Depending on their prior instruction, students may need additional support when working on questions 7 through 15. When you get to the graphing questions, you can review How to Make a Line Graph found on pages xx in the student book appendices.
- You can use the questions in the activity to help students begin to differentiate among constant speed (questions 2 and 3), changing speed and average speed (question 4), and instantaneous speed (questions 5 and 16). You may want to introduce these terms as you discuss each question.
- To help students achieve an understanding of these terms, you may want to discuss a car's speedometer, which many students will be familiar with. You can discuss a trip they may have taken and ask if they ever calculated their average speed on the trip; that is, the distance they traveled divided by the time it took to get there. Then ask them if they thought they were traveling at the same (or constant) speed for the whole trip. Most likely they did not, and they may even have stopped for lunch, so they should think about what that means in terms of their average speed. Then ask them how they might determine their speed at any single point in time during their trip; they will realize that the speedometer can be used. You can point out that while this speed is not an instantaneous speed, it is an average speed that was calculated using a small time interval—the time it takes the wheel to rotate. The smaller the time interval, the closer you get to a value of instantaneous speed.
- After students have completed this activity, review the answers in a class discussion and answer any questions students have about calculating speed or graphing so that students are ready to move on to the Experimenting and Investigating section.

Responses to Data Analysis Questions

- Using a copy of Table 2.1, fill in the missing data. Using the information in the first four rows of columns 3, 4, and 5 as models, calculate the data for the remaining rows in these columns. You will use this data to answer the remaining questions.

Table 2.1 Data Table and Calculations for FloJo's Record-Breaking Sprint

1	2	3	4	5
Distance from start (meters)	Time duration from start (seconds)	Time interval for each 10-meter segment of track (seconds)	Average speed for each 10-meter segment of track (meters/second)	Midpoint of time interval (seconds)
0	0			
10	1.80	1.80	5.56	0.90
20	2.90	1.10	9.09	2.35
30	3.90	1.00	10.00	3.40
40	4.85	0.95	10.53	4.38
50	5.79	0.94	10.64	5.32
60	6.71	0.92	10.87	6.25
70	7.63	0.92	10.87	7.17
80	8.56	0.93	10.75	8.10
90	9.51	0.95	10.53	9.04
100	10.49	0.98	10.20	10.00

- What might be some speeds found in a data table for FloJo's warm-up run? What speeds would be the same in the warm-up and in the race? What speeds would be different? *A similar table for a warm-up run would probably show much longer times, the same average speed for each 10-meter segment during the times she jogged at a steady pace, and varying average speeds during her practice sprints. Her warm-up sprint times would be similar to her race times, but her jogging times would not be.*
- Over which time interval were FloJo's average speeds constant? *Between 6.25 and 7.17 seconds, FloJo maintained a constant average speed.*
- By running 100 meters in 10.49 seconds, everyone agreed that FloJo was very fast. How fast was she? Examine the data in the chart and identify at which stretch in the 100 meters FloJo was running the fastest. At which stretch in the race was she the slowest? Explain why the fastest time was faster than the overall time might indicate. *FloJo was running the fastest average speed between 50 and 70 meters of her race—10.87 meters per second. Her slowest average speed was 5.56 meters per second. Her fastest time was during the segment of the race where she "turned it on," but she did not maintain this speed the entire time so the total time over the 100 meters was less because she was slower at the start and at the finish.*
- In question 4, you identified the segment when FloJo ran the fastest. Is it possible that she ran even faster than the data indicated? Explain your answer. *Yes. Because data were gathered at 10-meter intervals, it is possible she ran faster. Her average speed over the track between 50 and 70 meters was 10.87 meters per second. It is possible that at some point between 50 and 70 meters she was running slightly faster.*

6. If you were FloJo's coach, what would you tell her about where and how she might improve so she could go even faster? *Students may say that she should move faster at the start and not decrease her speed so much at the end of the race.*
7. Using the data from Table 2.1, plot distance against time from start. Place time on the horizontal axis. *See Figure T2.1.*
8. Mark a point on the line that shows when FloJo reached half the distance of the sprint. *See Figure T2.1.*
9. Mark a point on the line that shows when FloJo reached half the time of the sprint. *See Figure T2.1.*

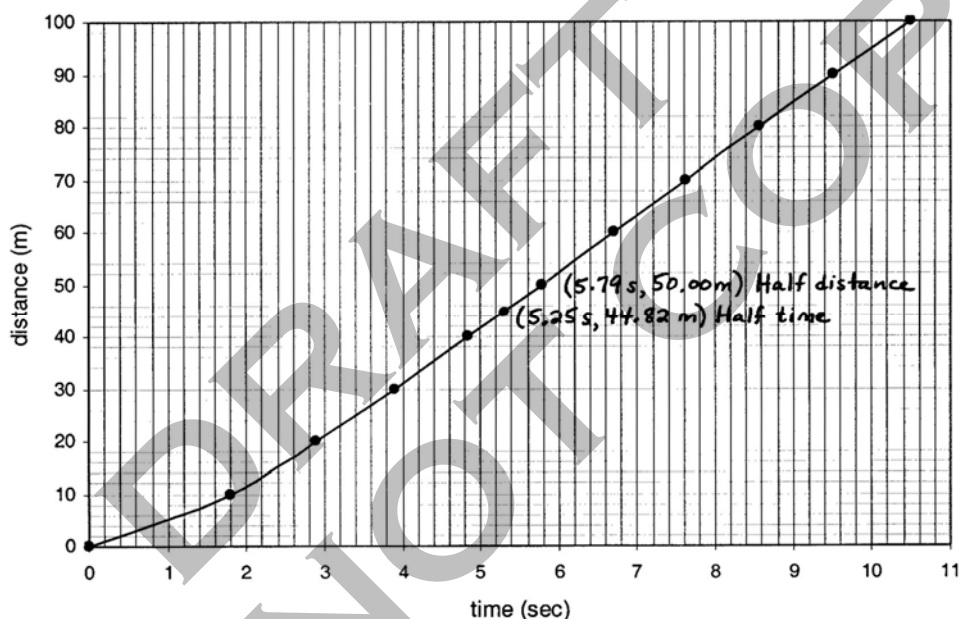


Figure T2.1: A graph of distance against time for FloJo's race. The graph is marked at the point when half the distance was run and at the point when half the time had gone by.

10. If the two points you just marked are not the same, explain why. *Since FloJo ran the second half of the race more quickly, the halfway point in distance and the halfway point in time can't be at the same point.*
11. Using the data from Table 2.1, plot average speed against time from start (the midpoint of the time interval). Place time on the horizontal axis. *See Figure T2.2.*

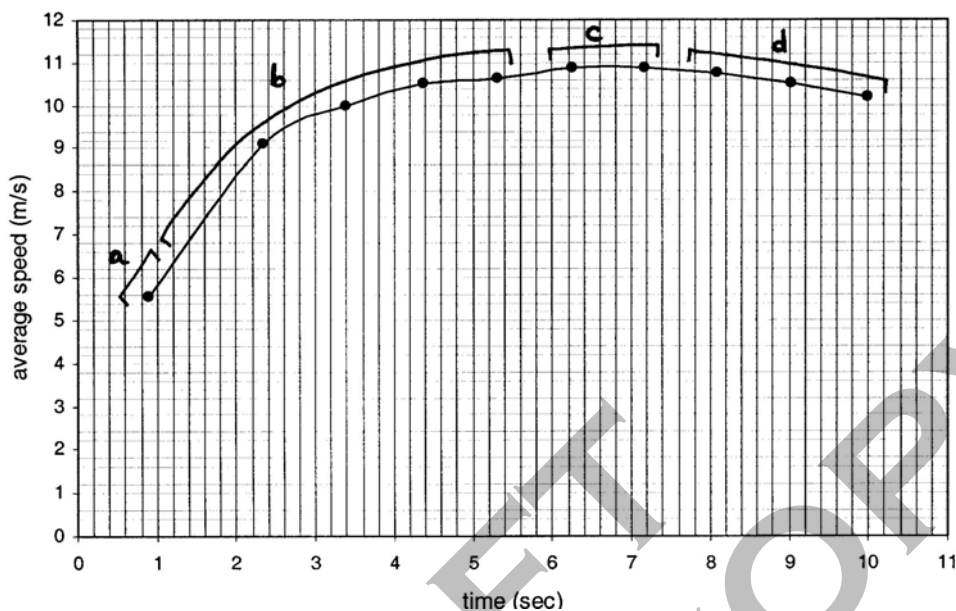


Figure T2.2: A graph of average speed against time for FloJo's race. The graph is marked as described in problem 12.

12. Mark the part of each graph that shows when: See Figure T2.2.
 - a. FloJo starts out slow at the beginning of the race.
 - b. FloJo goes faster and faster as she builds toward her fastest speed.
 - c. FloJo goes at her fastest speed, which she tries to maintain as long as possible.
 - d. FloJo begins to go slower and slower at the end of the race.
13. The timing device was triggered at 3.90 and 4.85 seconds by FloJo. Can you use the graph to estimate FloJo's speed at 4.00 seconds? Why or why not? *Yes, by determining the speed at that time from the graph, which can be estimated to be 10.40 meters/second.*
14. Which of the two graphs is better at showing her changes in speed? Why? *The graph of average speed against time is better. It more clearly shows changes in average speed because as the line goes up, stays steady, or goes down, the average speed is doing likewise.*
15. The timers measured FloJo's time at each 10-meter segment. What if timers were set up at every 5 meters? every 2 meters? How would this change the graph? *There would be more points to plot, and the graph would better represent what happened in the race. Draw students' attention to how more and more data points provide a more accurate graph.*
16. Does the data in Table 2.1 show FloJo's instantaneous speed? Why or why not? *Although FloJo takes only about one second to cover 10 meters, it is still an average speed that gets calculated. In theory, you could infinitely reduce the measurement intervals. That way, you could approach instantaneous speed. Have students do such a thought experiment to better understand the difference between average and instantaneous speed.*

SUGGESTED HOMEWORK

Have students read “Speed or Velocity?” This reading provides an explanation for the term “velocity,” which is commonly used as another word for “speed.”

Experimenting and Investigating

[Student Book page 16]

Purpose

Students use what they learned in Setting the Context to determine the speed of a classmate. Because they complete this work on their own, students understand better how to define, measure, and represent speed. Students will:

- Design an investigation to ascertain speeds.
- Measure, calculate, represent, and analyze speed.
- Translate between verbal, mathematical, and graphical descriptions of motion.
- Compare and contrast the information provided by verbal, mathematical, and graphical descriptions of motion.
- Recognize changing speed and constant speed from descriptions of motion.
- Differentiate between average speed and instantaneous speed.
- Consider direction as an additional measurement of motion.

Materials and Preparation

Each group of students needs:

- Devices available in your classroom that can measure time and distance

Each student needs:

- 1 copy of “Measuring Speed” Presentation Review Form (use Blackline Master 2-2)
- 1 piece of graph paper
- 1 calculator

CHALLENGE: How fast does your runner go?

Students continue investigating speed, but this time they will do so firsthand by using data they have generated and collected themselves. The challenge students are given is to monitor the performance of a student runner—either for the first 30 meters of a sprint or during the slow part of a warm-up run—similar to the way FloJo’s sprint was monitored.

First, groups discuss ways to meet the challenge. Second, each group creates its own plan to measure performance, decides what data it needs to collect, and describes how this will be accomplished in a step-by-step format. Students present their plans and get feedback from the class. Students see how well their planned investigation works by trying it out in a suitable venue. After students have completed their data collection, they describe the motion of a runner verbally in words and mathematically in data tables and graphs. They then analyze these descriptions of motion and draw conclusions about the performance of a student runner.

Students will need four to five 45-minute class sessions to complete the challenge.

SAFETY NOTES

- Make sure that student volunteers have running shoes. Sprints should only be performed by students who have had prior training in sports and only in a suitable outdoor venue. If you do not have students who have sports experience in your class, or you are completing the runs indoors, have students complete a slow warm-up run instead of a sprint.
- Because the investigation will be performed out of the classroom, thoroughly discuss the roles and responsibilities of each student and of the entire class. Set up clear expectations for behavior during the investigation.

Teaching Strategies

- Take the opportunity to elicit what students know about FloJo's run and how that applies to the challenge they have been given. Discuss the tools that runners and coaches use to analyze performance, and describe how this analysis can help runners increase competitive performance. In particular, for longer distance runs, athletes and coaches fine-tune their race strategies. They decide beforehand what speed should be maintained at which part of the race for the runner to accomplish his or her best time.
- For many students, writing is made easier if the writing task is discussed thoroughly in advance. For this reason, step 1 in the procedure is a group discussion; students discuss what they need to find out about the motion of their runner and how they might go about it. Continue the dialogue about what constitutes a good investigation as you review student groups' final plans in step 4. Also have students review each other's work using the "Measuring Speed" Presentation Review Form. This process, although initially time-consuming, will help students understand how to create a good investigation and aid them in becoming more skilled in creating their own procedures as they proceed through the module.
- Because this challenge has many steps, you may want to go through the steps with the students before they begin. Continue to keep students focused on the challenge as they complete each part of Experimenting and Investigating. Students will need to make many decisions about the kind of data they will collect and how they will collect it.

Facilitating the Challenge

Have students work in groups of four or five; each group should have a runner, timers, and a data recorder. You may wish to break down the procedure by having students complete steps 1 through 4 in the classroom, step 5 either at home or in the classroom, steps 6 through 10 at the place where the sprints will occur, and steps 11 and 12 either at home or in the classroom.

Below are some ways that you can facilitate particular steps of the challenge:

- 1: Encourage students to talk about their previous lab experiences and whether or not they have designed their own investigations or experiments.
- 2: Discuss the value of assigning roles ahead of time when students are writing their step-by-step procedures.
- 3: Have a discussion about what is meant by sources of error before discussing ways to remedy the errors. Possible steps that students could do to lessen error include practicing using the equipment, deciding on a consistent way to time the runner (do they measure when the

runner's foot or waist crosses a line, for example—a bright piece of tape could be placed on the foot or waist to facilitate the measurement), and determining how well different measurers compare with each other.

- 4: The experimental design must include a way to measure the time at the end of each 10-meter segment (although the segment could be less than 10 meters if there are enough people to time the run). This is critical in terms of graphing their data and comparing it to FloJo's run. After students have presented their investigation plans, you may want to take extra time to show students how to use measuring equipment like stopwatches or photogates.
- 7: To carry out practice runs, students could time the same person several times and compare those times. This person doesn't have to be the runner. Or two students could measure time at the same point on the track and compare their times.
- 12: Make sure that all students use the same scales on the axes when graphing speed against time. Have a quick discussion with students to determine the values of the highest speed and the longest time. By using the same scale, students can more easily compare graphs in the Processing for Meaning section.

Suggested Homework

As stated in the previous section, steps 5, 11, and 12 of the procedure can be completed at home.

Have students analyze their runner's description, data table, and graph by answering the Data Analysis questions. This work should be completed by the entire group, but each student must keep his/her own record of all answers, tables, and graphs.

Responses to Data Analysis Questions

1. How long did it take your runner to run the course? *Answers will vary from about 5 to 20 seconds.*
2. What was your runner's top speed? *Answers will vary.*
3. Compare the speeds of your runner over the first 30 meters to the speeds reached by FloJo over equivalent segments in the race or in the warm-up run. What do you notice? *Answers will vary but should include a comparison between FloJo's graph and the student's graph (e.g., although slower, they might accelerate over a similar distance before reaching maximum speed, etc.).*
4. What do the data and graph show about the changes in speed of your group's runner? How does the graph make it easy to show these changes? *The speed vs. time graph provides a visual picture of changes in speed that is easy to interpret at a glance.*
5. Your runner described the run. Compare and contrast the information you got from the runner with the information you get from the graph. *The graph shows average speeds, whereas the description explains how the runner felt the race was run. The data table and graph are objective, whereas the self-reflection is subjective. They may be in agreement or they may not because they are different ways to gather information.*

Processing for Meaning

[Student Book page 18]

Purpose

Students compare, analyze, and discuss their data, calculations, and representations of speed.

Students will:

- Describe and compare the motion of the runners using the graphs and the stories they created for the students' races.
- Interpret the mathematical information contained in the graphs in order to determine who is the fastest, the first to finish, and so on.
- Conclude how the distance measurement used affects the data collected.
- Explain how to predict an instantaneous speed using the graphs they created for the students' races.

Materials and Preparation

Make copies of each group's data table, graph, and runner's description so that every student has a copy of the work done by the class.

Listening for Understanding

Have representatives from each team report on their data and explain their representations of the data. Have them explain their process for analyzing their runner's performance from their data. Have students discuss any procedural or experimental errors they may have had. Encourage the class to ask questions about the investigation, the data, or the groups' conclusions. Then have students answer the questions posed in the student book and listen for the following kinds of answers from students:

1. Compare your graph to the graphs that other teams made. Are the shapes of the graphs the same or not? In what ways are they the same? In what ways are they different? *The answers to these questions should be mainly descriptive and should serve to focus students' attention on the major features of the graphs. It may lead to other questions if one graph is very different from another graph, which may be worth exploring before continuing on to the remaining questions.*
2. What information about each run does the shape of the graph tell you? *Students should look at the shape of each graph and from that shape determine the overall course of the runner's motion. They should use the language of mathematics as they describe the graph, indicating whether speed is increasing, decreasing, or staying the same. The data should be consistent with the terms they use.*
3. If the runners raced each other in a sprint race, how well would each do on the first 30 meters, based on the information you have about each runner? *Students should look at the data tables and the shapes of the graphs to see how each differs from other data tables and graphs. Students should find the runner who was the fastest at any time by identifying the graph that has the highest point on the vertical axis, which shows speed (assuming all students used the same scale). Students should find the runner who finished the 30 meters in the shortest amount of time by identifying the graph that has the earliest ending point on the horizontal axis, which shows time (again assuming all students used the same scale).*

4. Based on your data, could you predict the winner of a 100-meter race? Why or why not? *It isn't really possible to predict who would be the winner. Someone who may have a slow start could still reach a higher speed than the other competitors and even overtake them.*
5. What distance measurement did each group use? How can you tell? How does the length of the segment measured affect the information you get about a run? *Students should look at the data table or the points on the graph to determine information about distance measurements. Students should describe how the length of the segment affects the completeness of the data; shorter segments provide more complete data. Students should use the terms "average" and "instantaneous," and provide examples of what these terms mean.*
6. Each group measured speeds only at certain points during the runner's run. Can the graphs help you compare speeds at a certain time even if no measurements were actually made at that time? *Students should realize that they can use any point along the line of the graph to estimate the runner's instantaneous speed at any instant of time during the run. Use this question to clarify the difference between average and instantaneous speed.*

Teaching Strategies

- Before the discussion, have students organize all of their work from the learning experience and bring it with them to the discussion so that you can refer them back to earlier examples.
- Probe students' explanations and comments throughout the presentations and discussion of the questions without providing answers. Encourage peer comment and debate. Whenever students articulate their own understandings and listen to peers doing likewise, they are reformulating their own understanding of the concepts.
- Summarize the exchange at the end of this section by asking students to formulate definitions for speed, instantaneous speed, constant speed, average speed, and changing speed.
- You may want to return to students' original definition of speed that they created during the Setting the Context section. This comparison can help students see how much their thinking about speed has evolved during the course of the learning experience

Have students complete a report about their investigation. This work should be completed individually. Depending on students' prior experiences, you may want to provide an example of a completed investigation report that shows the work you want students to achieve. You can review the Investigation Report Format found on page A-5 in the student book appendices.

SUGGESTED HOMEWORK

Have students read the summative reading "Science, Sports, and Motion" to compare their experiences and ideas about speed with the story of FloJo. This reading ties together the concepts presented in the learning experience.

Checking Your Understanding

Assessment items for this learning experience are located in Appendix B and will be available on the Web site at the end of August. You may decide which items to use, when to use them (e.g., at the end of this learning experience or after a group of learning experiences), and how to use them (e.g., as quizzes, tests, or homework).

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