

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

LEARNING EXPERIENCE  
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## Prologue

Have you ever tried to invent something? An old saying states that “necessity is the mother of invention.” From the beginning of human history, people have invented devices to make life easier, safer, and more interesting. But how do people create inventions? They first see a need. The need may be essential, such as finding a way to provide a cheap, efficient source of light (the lightbulb by Thomas Alva Edison, 1880). Or, the need may be less than essential, even slightly bizarre, such as finding a way to prevent premature burials (the escapable coffin by Franz Vester, 1868). Some inventors may just begin by experimenting with materials and constructions, trying different ways of creating a gadget or device that will accomplish the desired task. However, most inventors take a more “scientific” approach and design devices based on certain principles of physics, chemistry, biology, or earth science.

Scientists seeking to figure out how the world works try to acquire an understanding of these basic principles. With no particular application or need in mind, these scientists carry out basic research. They want to know if there are rules which govern the way things happen in the world. They try to identify these rules by observing events, experimenting with materials, analyzing data, and organizing evidence. By understanding how the natural world works using basic research, scientists can also develop technologies that make the world a better place in which to live. In turn, these technologies and inventions become the tools they need to better understand the world through basic research.

In this learning experience, you invent a way to carry out a specific task such as turning on a lightbulb. Depending on your prior understandings, you may be an inventor that fiddles around until something works, or you may use your prior understandings of how things work to accomplish the task. Either way, the task should be fun and enlightening.

## Setting the Context



### Brainstorming

Just when you think that maybe there is nothing left to be invented, along comes something so new and different that it changes the way people live. In your lifetime, many inventions have come along that have made everyday life very different from when your parents were growing up. With a partner,

1. Make a list of at least 5 items that you think have been invented in the past 25 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.

Be prepared to discuss your ideas with the class.

Many of the items you listed in question 1 involve an understanding of physics. Physics is a fundamental part of everything you do and of the world as you see it through your senses. By understanding certain concepts in physics, you can describe the nature of motion, forces, energy, matter, heat, sound, and light.

### **ACTIVITY: Finding the Science in Art**

Inventors use physics to invent new devices, but understanding the physics behind how objects move can also be used to create works of art. A form of art called kinetic art uses different kinds of motion and energy to create moving, dynamic artwork. You may be familiar with a simple form of kinetic art, the mobile. Kinetic art can be fascinating, hypnotic, suspenseful, and surprising. In this activity, you watch the video *The Way Things Go*. In the video, two Swiss artists, Peter Fischli and David Weiss, use physical and chemical actions and reactions to create a mesmerizing series of chain reactions.

When trying to understand how events occur, scientists make very careful observations and record thorough descriptions of the events. Your task is to observe and describe events that occur in this work of art. In some cases, you may not see the event that caused an action (such as what makes a trash bag spin). You should try to infer or make a guess based on your observations of the event.

View this video at least twice.

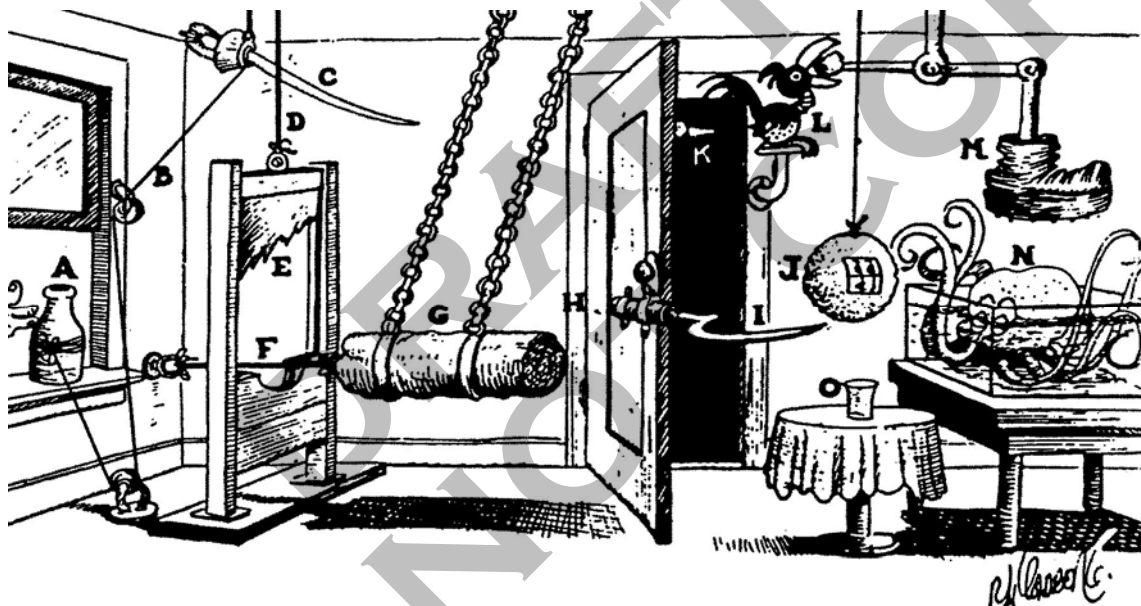
1. The first time you watch the video, watch and enjoy.
2. During the second viewing, make very careful observations about what is happening at each step. You may want to ask your teacher stop the video and replay or freeze a frame as you carefully consider each action. As you watch:
  - a. Take notes on the events.
  - b. Try to determine the cause of the event and the effect.
  - c. Some of the events that occur in the video involve chemistry – that is, events that have to do with the nature of matter and changes in the states of matter. Other events involve physics events – that is, events that have to do with motion, forces, and energy. Identify events in the video that you think involve chemistry and those that you think involve physics.
3. After the second viewing, use your notes to make a table with the column headings What Happened, What Caused the Event, What Effect It Had on the Next Step.

Be prepared to discuss your ideas and conclusions with the class.

## Experimenting and Investigating

### ACTIVITY: Doin' It, the Hard Way

Many of the actions that you observed in the video can be used to make something happen that is useful or makes life easier. As you determined in your discussion about inventions in the Brainstorming section, some of the understandings about physics have been used to develop devices and gadgets that make life easier. However, every once in a while someone comes along who takes delight in making a simple task as complicated as possible. Such a character was Rube Goldberg, an inventor and cartoonist. Goldberg would convert a straightforward task like squeezing an orange into a 15-step operation by applying concepts of physics of forces, motion, and energy transformations and the principles that govern them (see Figure 1.1).



**Figure 1.1** Rube Goldberg's Machine for Peeling an Orange. (A) A milkman lifts an empty milk bottle, which (B) pulls a string, causing a sword (C) to cut a cord (D), dropping the guillotine blade (E), which cuts the rope (F), releasing the battering ram (G), which swings and hits the open door (H), making it shut and causing the attached sickle (I) to slice off the end of the orange (J). At the same time, the spike on the shut door (K) sticks the bird holding a prune on a lever, causing the bird to squawk (L), thereby releasing the prune and causing the diver's boot (M) to drop on a sleeping octopus (N), which wakes up in a rage, and seeing a diver's face painted on the orange, crushes it with its tentacles, causing the orange juice to pour into a glass.

From Rube Goldberg by Maynard Frank Wolfe Simon and Schuster New York 2000  
Permission pending

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

How many times a day do you flip a wall switch or a lamp switch to light up a room? How many times do you turn off your alarm clock or turn on a radio? Doesn't it get a little boring doing things the same old way after a while? In this activity, you make a simple task more interesting by designing a machine that can perform the task for you, using at least 10 steps. In the first part of the challenge, you and your team will design the machine. At the end of the semester, you will redesign your machine based on the understandings of motion, forces, and energy that you have learned during the semester. You will then build a working model.

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**Procedure**

1. With your group, decide on a task that your machine will carry out. You may choose from a list provided by your teacher or decide on your own. Check your choice with your teacher.
2. Each member of the group should prepare a sketch of a design he or she thinks might achieve the challenge. The device must have at least 10 steps. A step is a single event, such as a ball rolling down a ramp or a spring being triggered by something hitting it. Brainstorm these designs and come to a group decision about the final design. As you brainstorm take into consideration:
  - The kinds of materials you might need and their availability. Try to use common items found around the house, classroom, or garage.
  - The specific actions or steps you want to include and how difficult they are to achieve and reproduce consistently.
  - Whether one action can trigger another action easily (e.g., can a ball rolling down a ramp knock over a board that will trigger a spring?).

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**SAFETY NOTE**

Do NOT include any of the following in your design: live animals, explosives, fire, or noxious chemicals.

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Once you get some ideas about how your machine will work, make a list arranged in order of the steps, or draw a simple picture of the steps. It may help to work backwards from the final step (achievement of the task). One of the key components of any Rube Goldberg machine is humor and wackiness, so let your imagination go a bit wild. **But keep in mind that you may be building this machine at the end of the course so try to stay real.**

3. As a group, decide on your final design. Then prepare a sketch that shows your design, the materials you plan to use, and a numbered, step-by-step description of each step.
4. Identify where you think motion, forces, and energy are involved in your device. If you have included any actions involving chemistry, biology, or earth science (such as making a bird squawk or angering an octopus), identify those also. Think about the discussion you had following the video and the kinds of events you identified. Label these places on your sketch. **Remember, the final step must achieve the task you set out to do, such as turn on a lightbulb.**

5. Prepare to present your design to the class. As part of your presentation include:
  - The task your machine will carry out
  - A description of the action or event that takes place at each step
  - A detailed explanation of the motion, forces, or energy involved at each step

For example, you may design a machine that turns on a lightbulb, and two of the steps involve a ball rolling down a ramp and hitting a line of dominoes, causing the dominoes to fall. You might identify motion in the ball rolling down the ramp and that motion may involve energy and increasing speed. When the ball hits the first domino, that event involves energy; energy is transferred from the ball to the domino, and the domino falls over.

6. After your presentation your classmates will provide suggestions and comments on your design. Be sure to record their feedback in your notebooks because you will be referring to it as you redesign your machine at the end of the course.

## Processing for Meaning

In addition to your own presentation, listen carefully to the presentation of other groups and provide helpful feedback to them. Presenting ideas about an experiment or design to others is an important step for scientists. Often, others can identify things you didn't, or their experiences have taught them what might or might not work in an experiment or design. Comments, questions, and advice should be helpful and positive.

### Discussion

When providing feedback to other groups, discuss:

- Whether they think their machine can really be built and why
- Events or actions that might be problematic, that is, that might not do what they think it should
- Suggestions for streamlining or improving the machine
- Other ideas about the motion, force, and energy that take place at each step

### READING: Phantasmic\* Physics

The contraptions that Rube Goldberg (and now you) designed are excellent examples of the application of physics. Every action involves some aspect of energy transfer, energy transformation, motion, or force. The principles that govern these are evident everywhere you look, not only in devices built by humans, but also in every aspect of the natural world around you. Look out the window of your classroom or home and you will see these principles in action—in clouds scudding across the sky, a tree bending in the wind, birds flying, wood burning in a fire, a dog racing after a thrown stick, stars glowing in the night sky, an apple falling from a tree. All your life you have been observing these kinds of events happening; objects falling down, objects hitting each other, objects moving until they stop or are made to go again by some force. You may have also developed your own explanations for these observations and experiences as a way of understanding how the world works.

As you continue your exploration of physics, you may find that some of the laws of physics do not make sense based on your prior observations and conclusions. These laws may actually seem counterintuitive; that is, they may run contrary or opposite to how you think events happen. For example, it may be hard to believe that objects fall to earth at the same increasing rate of speed no matter what their masses are. Or that when you lean against a wall, the wall is actually pushing on you, and the heavier you are, the more the wall will push on you. In some learning experiences, you may make a prediction, carry out an experiment, and find that the outcome is the exact opposite of your prediction. Or you may read about a scientific principle that seems totally opposite from your experience in real life. You may also make an accurate observation of a principle in physics and still find it hard to believe. Much of this can be explained when you start to look more closely at actions or events. Certain events that don't seem obvious to you at first may make more sense when understood at the atomic or even subatomic level.

If any of this happens, you need to carefully assess the event:

- Think about your own ideas and compare them to the scientific explanation.
- Think about how your observations may not tell the whole story.
- Try to make connections between the scientific principle you are exploring and how it is used or played out in the real world.
- Break down the event into its different parts and try to determine the factors that may affect the event.
- Quote Albert Einstein who said “The more I know the more I realize I don't know.”
- Above all, ask questions, of yourself, of your fellow students, of your teachers and of any others you can interest in the topic.

Discovering and understanding the laws of nature involves detective work, and as any good detective knows, asking questions, collecting and analyzing evidence and keeping an open mind are all critical to finding out who, what, when, where, and how of any mystery.

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

# Unit 1

# Laws of Motion

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# Unit 1: Laws of Motion

## Overview

What do a 100-meter sprint, a game of pool, and a wheelchair marathon have in common? They all involve motion—a phenomenon that is central to the study of physics. In this unit, you will begin to understand the laws that govern motion by running in one direction, making a tricky pool shot, and investigating how balls or carts go faster and faster when they roll downhill. You'll complete the following learning experiences:

**Learning Experience 2:** Have you ever thought about your own motion? For instance, how fast can you run? How do you know your speed? In this lesson, you will study the story of an outstanding, record-breaking, 100-meter race. You will find out how to determine and represent the runner's speeds at various times during the sprint. Then you will measure your own motion and use that data to determine and represent your own speeds.

**Learning Experience 3:** What do you think causes changes in speed or direction? For instance, what do you have to do to make a pool shot? In this lesson, you'll see the set-up for an incredibly difficult pool shot featured in a movie. You'll hone your pool skills by carrying out your own investigation into the motion of pool balls as you attempt to “sink” a pool ball. You'll use your knowledge of how the speed and direction of the pool balls will change under different conditions to determine what events cause the change in motion you observe.

**Learning Experience 4:** How can you control your speed change when you're going uphill? downhill? Can you predict speeds? In this lesson, you'll explore the story of two wheelchair racers competing in a marathon and determine what aspects of the racer, wheelchair, or course can affect speed. Using balls or carts on a ramp, you'll design experiments to investigate downhill motion. Then, by analyzing your data, you'll be able to predict changes in motion in different circumstances.

Well, it's time to get moving with Unit 1. Have fun!

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# A Perfect Race: Measuring Changes in Motion



## Prologue

Have you ever run a race against opponents? If so, your goal was probably to run the distance in the minimum amount of time possible, or at least in a time less than that of your opponents. If the distance was short, such as across the playground, you probably ran as fast as you could for as long as you could. Did you ever wonder exactly how fast you were running? Do you think your speed was the same for the entire race, or did your speed change during different parts of the race? Coaches and runners often analyze how speeds change in a race in great detail to determine how they might improve a runner's performance.

In this learning experience, you will study a remarkable race run by one of the great female runners, Florence Griffith Joyner (FloJo), to find out her speeds at various times during the 100-meter race. You will then run your own time trials and find out your speeds. These investigations will give you a deeper understanding of the concept of speed and provide you with ways to measure, calculate, analyze, and represent speed in words, numbers, and graphs.

## Setting the Context



### Brainstorming

1. What kind of running experiences have you had?
2. How did you run in each circumstance?
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?
4. If you wanted to find out your speed, what would you have to know? How would you calculate your speed?
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?
6. The story you are going to read in the next section is titled, "FloJo: The World's Fastest Woman." Have you heard of FloJo? What can you tell the class about her?

In 1988, FloJo, a powerful and flamboyant sprinter, broke the women's world record for the 100-meter race by running 100 meters faster than any woman had ever run it. But does that mean she ran faster than any woman had ever run before? Did her speed for the 100 meters truly reflect her actual speed over the entire distance? That is, was she running faster or slower during different parts of the race? To answer this question, you can take a closer look at the data from the race, which follow the story of FloJo's record-breaking run.

## STORY: FloJo: The World's Fastest Woman

July 16, 1988, was an extremely hot, humid, and windy day in Indianapolis—not ideal conditions for the women running the quarterfinal 100-meter race at the U.S. Olympic Track & Field Trials. At the beginning of the day, the 100-meter world record of 10.76 seconds set in 1984 belonged to Evelyn Ashford.

While waiting to run the race, the women runners warmed up for about 20 minutes. They started by jogging a few laps around the stadium. Dressed in a purple one-legged outfit and sporting long bright fingernails, FloJo focused on maintaining a steady pace, which was about half the speed she would achieve during a race. Running down the track at a slow but constant speed helped her to relax, find her breathing, and warm up her body. Her mind concentrated on the upcoming race. Every so often she would interrupt the slow steady pace of the warm-up routine with a few sprints to fire up her muscles.

Then it was time for the race. No one could have anticipated how FloJo was about to shock the track-and-field community. Even though she was better known for running the 200-meter, FloJo completed the 100-meter race in 10.60 seconds to beat Ashford's record. The crowd went wild while her competition stared at the clock in amazement. To the audience's dismay, the measurement of the tailwind on the track was higher than the maximum allowed (2.00 m/s), and the announcement that FloJo's time had been thrown out was met with loud boos. But achieving such an incredible time convinced FloJo that she could push herself to run faster than she ever thought possible, even without the help of a tailwind. The race would have to be repeated.

Again, the runners lined up at the starting line, crouched with their feet in the starting blocks. The starting gun let out a loud CRACK as the judge pulled the trigger, and FloJo exploded from the starting blocks. With her body in a low forward-leaning position, she took smooth, short steps that lengthened as she gradually straightened up. By 10 or 15 meters, each of FloJo's steps grew in length, and she evened out her stride as she tried to increase her speed as much as possible.

By 50 meters into the race, FloJo had a huge lead as she tore down the straight 100-meter track. FloJo was still increasing her speed by driving her arms hard and fast, running nearly at maximum speed. According to the measurement devices on the track, she reached her maximum speed of 10.87 meters per second (over 24 mph!) and worked to hold that speed as long as possible, knowing she could not maintain it for long. During the last 15 meters of the race, FloJo focused on minimizing how much she slowed down by relaxing her limbs and trying to maintain perfect



technique. She knew that exerting too much effort in this stage would cause her muscles to tighten, slowing her down at a quicker rate.

As FloJo crossed the finish line, the clock stopped at 10.49 seconds. A hush went over the crowd because FloJo's time was so unbelievably fast. Everyone, including FloJo, assumed the tailwind must have been strong again. "When I saw the time, I couldn't believe it!" said an amazed FloJo. All of the racers and fans turned to look at the wind gauge—it read 0.0! As the crowd realized that her record-breaking time would stand, they let out a deafening roar. FloJo was thrilled with her performance, saying, "I had a good start, a relaxed middle, and kept my knees up at the end. It was more or less a perfect race." She later finished the Olympic trials by running a 10.70 in the semifinals and 10.61 in the final, both of which also beat Ashford's record time.

### Thinking About What You Read

Write your responses to the following questions.

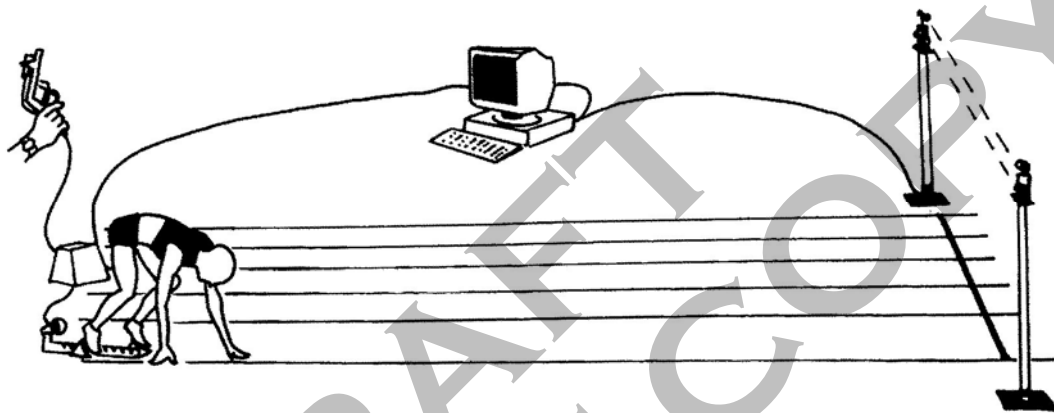
1. Prior to the race, FloJo did a warm-up run. How did her speed in the warm-up run differ from her speed in the actual race?
2. Develop a visual way to show her speeds in the warm-up run and her speeds in the actual race.
3. FloJo said, "It was more or less a perfect race." What do you think she meant by that comment? What do you think a perfect race would look like?
4. How would you explain what speed is?
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?
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?

### ACTIVITY: FloJo's Stats

How fast did FloJo actually run? The story indicates that she ran the 100-meter race in world record time—10.49 seconds. But did she, in fact, run faster or slower than that at any points in the race?

After a race, the coach and runner examine every aspect of the race to figure out how the runner's performance might be improved. They often use video analysis of the race to look at the technique and the speed at various crucial points during the race. This valuable type of analysis shows the athlete's strengths and weaknesses, and provides information for future training and race strategies.

In the following activity, you will examine various data points collected during FloJo's famous race so you can analyze her race. How perfect do you think her race was based on the data? Because FloJo's race was over in less than 11 seconds, her data was timed by a system that can measure hundredths of a second. These systems usually consist of a clock triggered by the starter's gun, a light source that sends a light beam across the track, and a device that stops the timer when a runner passes through the light beam. Figure 2.1 shows how a timing device works.



**Figure 2.1:** Races are timed with automatic timing devices that can measure hundredths of seconds.

Table 2.1 shows the data collected during FloJo's run, the subsequent calculations that were used to determine her speed for each 10-meter segment, and the approximate time she reached that speed.

**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 the 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			
60	6.71			
70	7.63			
80	8.56			
90	9.51			
100	10.49			

## Data Analysis

With your group, complete the following questions. Be prepared to share your answers with the rest of the class.

Columns 1 and 2 of Table 2.1 provide the *raw data* from FloJo's race, that is, the actual data that were collected from the race. Column 1 shows the distance traveled from the start in 10-meter intervals, while column 2 indicates the time it took FloJo to travel that distance, as determined by the timing device. For example, it took 1.80 seconds to travel the first 10 meters; 2.90 seconds to travel 20 meters, 3.90 seconds to travel 30 meters, and so on.

Columns 3, 4, and 5 indicate how the raw data can be worked with mathematically to give other kinds of information. Column 3 shows the time interval it took for FloJo to travel each 10-meter segment. For example, it took FloJo 1.00 second to run the 10-meter segment between the 20- and 30-meter positions on the track. Column 4 indicates her average speed over this 10-meter segment. It is calculated by dividing the distance of the segment of track, which is 10.00 meters in every case, by the time it took FloJo to run those 10 meters, which in this segment was 1.00 second. The average speed is the distance divided by the time interval, which in this segment is 10.00 meters divided by 1.00 second, which gives an average speed of 10 meters per second.

The data in column 5 is the halfway point of the time interval (also called the midpoint of the time interval). It is assumed that this time is an approximation of the time when FloJo reached her average speed for each 10-meter segment of track. You 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, over the segment of track from 20 meters to 30 meters, you can see that FloJo ran at an average speed of 10.00 meters per second. The approximate time she reached that speed would be calculated by adding 2.90 seconds + 3.90 seconds and dividing by 2 to get 3.40 seconds.

1. Using a copy of Table 2.1 (your teacher will provide this), fill in the missing data. After reviewing the above explanation about data analysis, use the information in the first four rows of columns 3, 4, and 5 as models, and calculate the data for the remaining rows in these columns. You will use these data to answer the remaining questions.
2. 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?
3. Over which time interval were FloJo's average speeds constant?
4. By running 100 meters in 10.49 seconds, everyone agreed that FloJo was very fast. Examine the data in the chart and identify 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.
5. 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.

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?

Besides placing data into tables and doing calculations, data are often represented visually through *graphs*. Graphs can make it easier to compare data from different races quickly and easily, and to get an idea of the running pattern of each race. When the instructions below say to "plot," that means to make a graph.

7. Using the data from Table 2.1, plot distance against time from start. Place time on the horizontal axis.
8. Mark a point on the line that shows when FloJo reached half the distance of the sprint.
9. Mark a point on the line that shows when FloJo reached half the time of the sprint.
10. If the two points you just marked are not the same, explain why.
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.
12. Mark the part of each graph that shows when:
- FloJo starts out slow at the beginning of the race.
  - FloJo goes faster and faster as she builds toward her fastest speed.
  - FloJo goes at her fastest speed, which she tries to maintain as long as possible.
  - 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?
14. Which of the two graphs is better at showing her changes in speed? Why?

In reality, FloJo's speeds may vary slightly every instant as she runs. (An instant is a single point in time, for example, a single clock reading.) Scientists call these speeds *instantaneous speeds*. However, we only time FloJo every 10 meters. Therefore, the speed in column 4 is an average of FloJo's speeds over each 10-meter interval. Scientists call this speed an *average speed*.

15. The timers measured FloJo's time at each 10-meter segment. What if timers were set up every 5 meters? every 2 meters? How would this change the graph?
16. Do the data in Table 2.1 show FloJo's instantaneous speed? Why or why not?

### **READING: Speed or Velocity?**

You've probably heard the word "velocity" used in the context of science. Perhaps you've heard the phrase "terminal velocity," or "high-velocity," for example. Most likely the context didn't really give you a clue as to what velocity means. So what exactly is velocity? Read on to find out!