PART ONE

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The Nature of Biology

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Part I will begin our inquiry into biology by considering what biologists do. In general, biologists ask and answer questions. We begin with the sorts of questions biologists ask and how they try to answer them.

CHAPTER

What Is Biology?

This chapter addresses the following questions:

What Is Biology's Main Goal?

Why Do Biomes Change from Place to Place?

How Do People Answer Causal Questions?

How Can We Test the Sunlight Explanation?

How Are Biological Explanations Tested?

Why Do Giraffes Have Long Necks?

Why Do Gazelles Leap When Being Chased?

How Did Caro Test the Drawing-Attention Explanation?

How Did Caro Test the Signaling Explanation?

Box 1.1 Connecting Science and Mathematics: Combinatorial Reasoning and Generating Possibilities

Box 1.2 Connecting Science and Mathematics: Probability and Random Sampling

What Is Biology's Main Goal?

Biology is often defined as the study of life. But how do people study life? How do people actually *do* biology? Let's begin with a story about a teenager named Kris who began doing biology without even knowing it.

Kris grew up by a lake in northern Michigan. As a teenager, she had never traveled west and was eager to see the western United States. So when her family planned to vacation in Arizona, Kris was delighted. The trip from Michigan to Arizona was unforgettable. As Kris and her family drove south, the northern forests (Figure 1.1a) first gave way to farmland and rolling hills of southern Michigan and then to the cornfields of Illinois (Figure 1.1b). They then drove through the hills of Missouri and on to Oklahoma. By the time they reached Oklahoma, a big change had taken place. Eastern Oklahoma was green, but its trees were short and it was getting hot and dry. When they reached western Oklahoma, grass was about all there was to see. The Texas Panhandle seemed drier still. It also seemed hotter, flatter, windier, and had even shorter trees (Figure 1.1c). When they entered New Mexico, the grasslands had given way to small scrubby bushes and bare ground. By the time they reached southern Arizona, the sky was cloudless and it was broiling hot! The desert around Tucson was filled with rocks, strange looking cacti, and dry gravel creek beds (Figure 1.1d).

Kris's trip made a big impression on her. But she was about to take another trip that would make an even bigger impression. Soon after arriving in Tucson, Kris and her family decided to explore the Catalina Mountains just north of Tucson. A narrow road winds up the Catalinas to a peak called Mt. Lemmon, over 9000 feet in elevation.

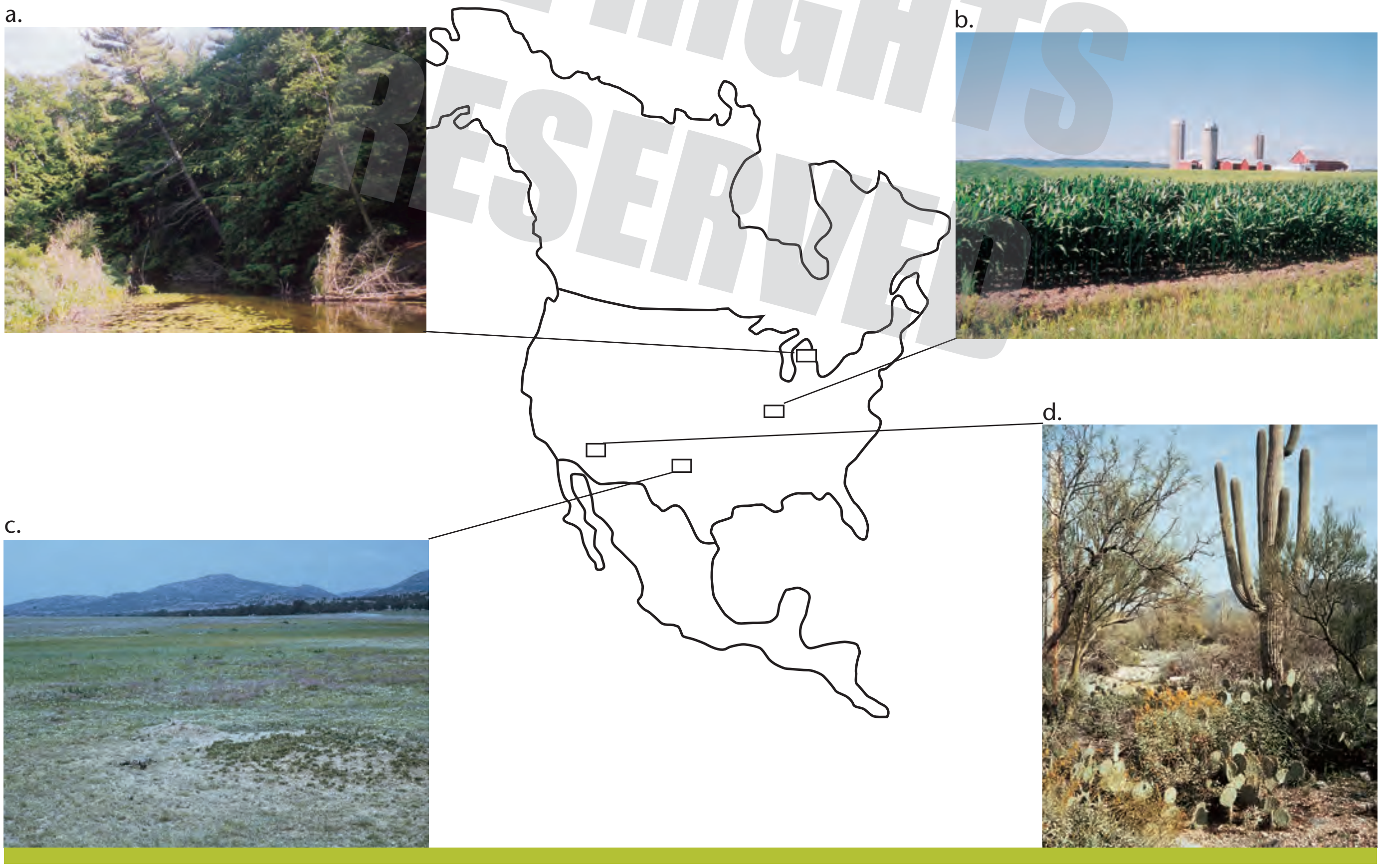


FIGURE 1.1
a) Michigan forest b) Cornfields of Illinois c) Texas Panhandle grassland d) Southern Arizona desert.

Kris found nothing surprising about the base of the Catalinas at about 2000 feet in elevation. The base looked like a desert—just like the rest of the area around Tucson. But as they began their ascent, it quickly became apparent that this would be no ordinary desert drive. In fact, by the time they climbed to 3000 feet, the desert was gone! Instead, short bushes and grasses were everywhere. As they continued their ascent, larger bushes and short scrubby trees appeared (Figure 1.2a). The vegetation looked like they were on the way back to Michigan and gotten to Oklahoma! By the time they hit 5000 feet, the air was decidedly cooler and they were in a broad-leaf forest. And by the time they reached 7000 feet, they were in a pine forest that looked just like northern Michigan. Even more amazing, after they climbed a little further, they came to the Mt. Lemmon Ski Valley (Figure 1.2b)!

b.

a.

FIGURE 1.2
a) Mt. Lemmon Arizona at 3000 feet. b) The Mt. Lemmon Ski Valley at over 7000 feet.

Thanks to her cross-country trip and her ascent to Mt. Lemmon, Kris made a number of **puzzling observations** that raised a number of questions. For example: Why do evergreen and broad-leaf forests dominate Michigan while grasslands dominate western Oklahoma and Texas and a desert dominates southern Arizona? Why do vegetation types change as one travels up a mountain? Also, why are these mountain changes like the ones seen when traveling across the country? And how can it snow in southern Arizona?

Kris's questions inquire into the causes, the "whys," of things, and thus are called **causal questions**. Causal questions seek causes—explanations—for puzzling observations. Causal questions differ from the "who," "what," "when," and "where" questions that aim to describe, so-called **descriptive questions**. Certainly, answering descriptive questions is important. But one can describe a situation and still not know why it happened. In other words, Kris may know *what* kinds of plants live at different elevations on Mt. Lemmon, but not know *why* they live at those different elevations.

key ideas

puzzling observation An observation that is unexpected thus provokes one to seek an explanation—a cause for the unexpected observation.

causal question A question inquiring into the cause or causes of some phenomenon. For example: Why does vegetation change from place to place? Why is it hotter in Arizona than in Michigan? Why is it cooler at the top of mountains than at the bottom? How can it snow in Arizona?

descriptive question A question inquiring into the who, what, when, where—but not why—of some observed object, event, or situation. For example: What types of vegetation changes occur as one travels from Michigan to Arizona? When did Kris's family travel up Mt. Lemmon? Where are the Catalina Mountains?

So Kris explored nature and made new and puzzling observations, observations that raised causal questions. In this sense, Kris was acting just like a biologist, as this is what biologists often do. Kris's trip demonstrates another important aspect of biology: Finding different vegetation types in different places, or in the same place when *key ideas*

biome A broad area of the Earth's surface characterized by distinctive vegetation and associated animal life; for example, broad-leaf forest biome, grassland biome, desert biome.

biosphere The region of the Earth, including land, air and water, that supports life, all of the Earth's biomes.

traveling up a tall mountain, is universal. In fact, biologists have given names to broad areas with their own distinctive plant and animal types. They are called **biomes**, with names such as the evergreen forest biome, the broad-leaf forest biome, the grassland biome, and the desert biome. Figure 1.3 shows the world's major biomes, and Figure 1.4 shows how these biomes vary with elevation (i.e., with altitude) and with distance from the equator (i.e., with latitude). The region of Earth where life exists—where all of the biomes exist—is called the **biosphere**. The biosphere is a layer only fourteen miles thick centered roughly at sea level, a layer that includes the highest mountains and the deepest ocean trenches.

Why Do Biomes Change from Place to Place?

Once puzzling observations are made and causal questions are raised, one seeks answers. How do biologists answer causal questions? Do they simply observe? This may sound like a good idea because making observations clearly plays a role in raising causal questions. Does observation also play a role in answering them? And if so, what is that role? Let's try to answer these questions by finding out how biologists discovered why biomes change from place to place.

In 1855, while pondering biome differences, French biologist Alphonse de Candolle came up with an idea. Perhaps, thought de Candolle, biomes differ from place to place because of climate differences. More specifically, temperature and moisture differences might *cause* biome differences. For example, a hot/dry climate might pro-

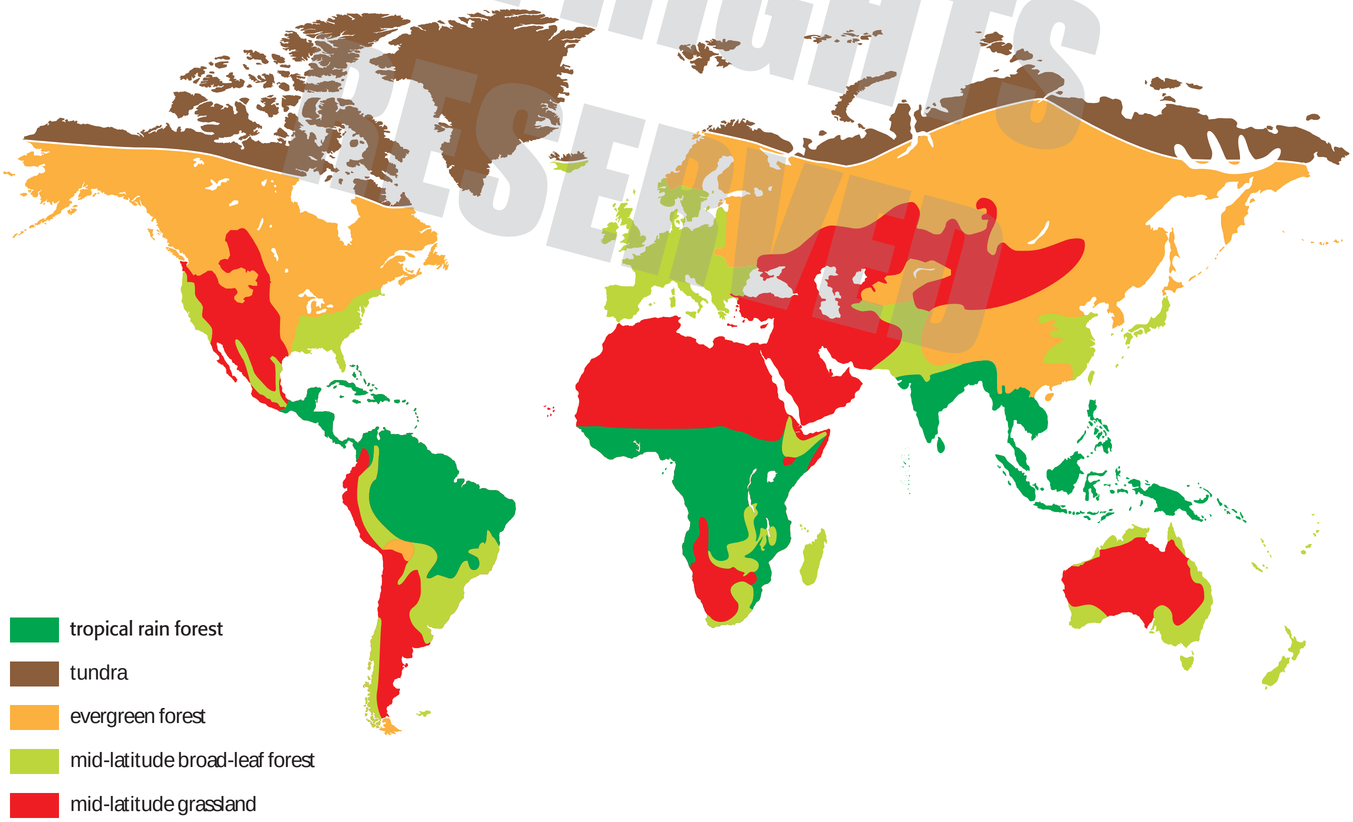


FIGURE 1.3
The world's biomes.

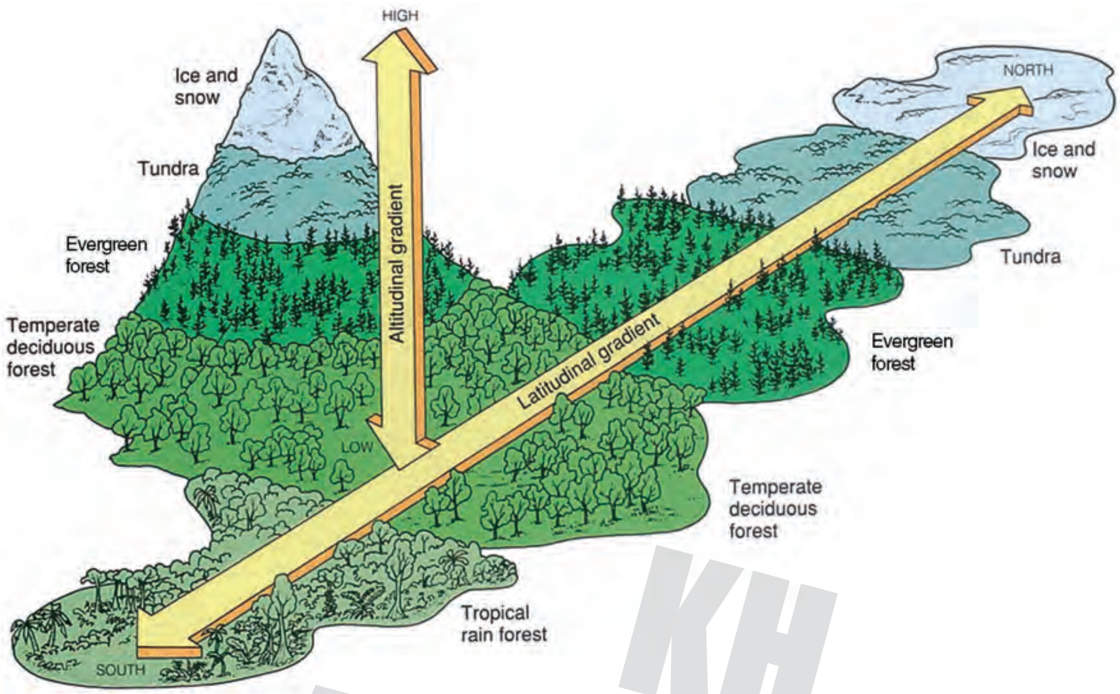


FIGURE 1.4
Why do biomes vary with elevation and with distance from the equator?

duce a desert biome. A cool/wet climate might produce a broad-leaf forest biome, and so on. It took nearly thirty years before another biologist named Vladimir Koppen figured out a way to test de Candolle's temperature-moisture explanation. To start, Koppen developed a climate classification system based on temperature and moisture differences. To identify climate types, Koppen divided temperature into three ranges: cold, warm, and hot. He also divided moisture into three ranges: dry, moist, and wet. He then generated all possible combinations of ranges to give nine climate types: cold/dry, cold/moist, cold/wet, warm/dry, warm/moist, warm/wet, hot/dry, hot/moist, and hot/wet (see Box 1.1). To this list of nine climate types, he added information about whether rain fell primarily during summer, during winter, or whether it fell throughout the year. Koppen then searched for a link between climate type and biome type. To do so, he mapped his climate types and compared them to where the biomes were found. Koppen reasoned that *if* prevailing temperatures and amounts of moisture really do *cause* biome type, *then* a map of his climate types and a map of biome types should overlap.

With so many climate types, Koppen's climate maps were quite complex. But take a minute to look over Figure 1.5. The figure shows a simplified climate map based on Koppen's system in which only five climatic types are drawn (cold/dry, cold/wet, intermediate, hot/dry, and hot/wet). Now compare Figure 1.5 with Figure 1.3, which maps the world's major biomes. As you can see, comparison of the two maps shows considerable overlap. Because this overlap is what de Candolle's explanation led Koppen to expect, de Candolle's explanation seemed to be on target. In other words, we have evidence that biome types are caused by temperature and moisture differences!

But why do biomes change as one travels up high mountains? Could these biome differences also be caused by temperature and moisture differences? In spite of the fact that the top of a high mountain is minutely closer to the sun than its base, it is cooler at the top. It also rains or snows more at the top. Consequently, it appears that de Candolle's temperature-moisture idea can also explain why biomes change with increasing elevation. But why is it cooler and wetter at the top? This is a relatively

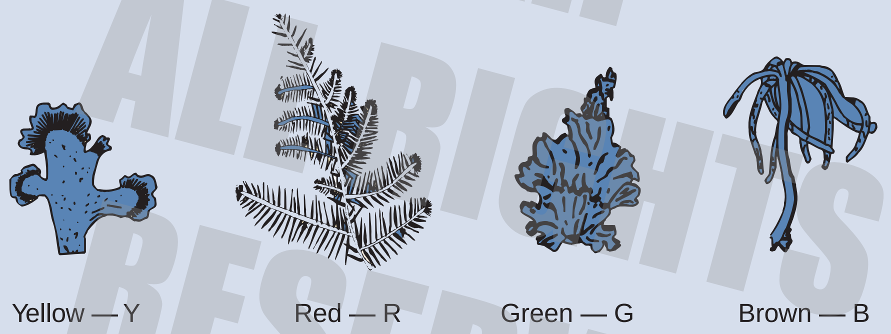
box 1.1 Connecting Science and Mathematics: Combinatorial Reasoning and Generating Possibilities

When trying to test de Candolle's climate explanation for biome differences, Vladimir Koppen developed a climate-type classification system based on temperature and moisture differences. To do so, he combined cold, warm and hot temperatures with dry, moist, and wet moisture conditions to produce nine climate types (i.e., cold/dry, cold/moist, cold/wet, warm/dry, warm/moist, warm/wet, hot/dry, hot/moist, and hot/wet). When trying to test explanations, people often need to generate possible combinations like these. For example, suppose you wake up in the morning with a headache. What could have caused it? Was it the cold air streaming in from the open window? Was it the hard pillow? Was it stress from doing too much homework the night before? Or perhaps it was some combination of the three (i.e., air and pillow, air and homework, pillow and homework, air and pillow and homework). Or perhaps it was something else!

The following two puzzles (the Algae Puzzle and the Buttons Puzzle) are provided to give you an opportunity to try your hand at generating possible combinations. When attempting to generate all possibilities, see if you can discover a systematic plan. When finished, compare your answers and plan with those of a few other students. You can also compare them to the answers that appear on page 697.

The Algae Puzzle

A population of crabs that eats algae lives on the seashore. Four kinds of algae are on the seashore: yellow, red, green, and brown algae (shown below).



Dr. Saltspray, a biologist, wants to know which type(s) of algae are being eaten by the crabs. She plans to find out by cutting open the stomachs of some of the crabs and looking to see which type(s) of algae are inside. But before she cuts open the crabs, she lists all the different algae diets she thinks possible. Write down each possible algae diet she might find. Use letters Y, R, G, and B to save space.

The Buttons Puzzle

The drawing below shows a box with four buttons numbered 1, 2, 3, and 4, and a light bulb. The bulb will light when the correct button or combination of buttons are pushed. Your problem is to figure out which button or buttons (pushed at the same time) make the bulb light. Make a list of the buttons and all the possible combinations of buttons you would push to figure out how to make the bulb light.

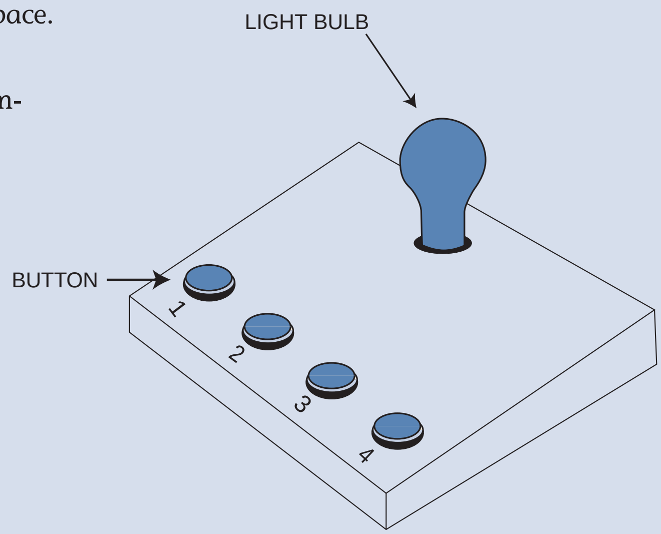


FIGURE 1.5
Vladimir Koppen's climate map. How do Koppen's five climate types compare with the biomes shown in Figure 1.3?

difficult question, so we will save it for Chapter 18 after some additional ideas have been introduced. For now, it is enough to say that biology is mainly about making puzzling observations, raising questions about cause-effect relationships (i.e., causal questions), and trying to answer them generating and testing possible explanations. To learn a bit more about how people generate and test possible explanations, let's turn to a familiar situation.

How Do People Answer Causal Questions?

When Renee's son was a baby, he sometimes woke up crying very early in the morning. As you can imagine, this presents a problem for sleepy parents. Why was the baby waking up and crying so early? Renee and her husband desperately wanted to know so they could get him to sleep longer. A few ideas occurred to Renee. It was summer and the sun was streaming through the baby's window early. So perhaps sunlight was the cause. On the other hand, the baby wanted milk when he woke, so perhaps hunger was awakening him. At the time Renee and her husband lived in a duplex and the neighbor was often up early, banging around. So perhaps the neighbor's noise was the cause. Although you may be able to suggest other possibilities, these seemed the most likely. Thus, three possible explanations have been generated that might answer the causal question: Why was the baby waking up so early? Once an explanation has been proposed, it must be tested. How is this done? Let's return to the example.

How Can We Test the Sunlight Explanation?

Suppose Renee's baby is waking because of the sunlight streaming through his window. What would you expect to happen the next morning if a heavy blanket is hung over the baby's window to block the sunlight? If the sunlight is the cause, and we block the sunlight, then the baby should sleep longer the next morning. But suppose the reason he is waking is his hunger. If so, then the blanket should have no effect. The baby should still wake up early. The argument looks like this:

If . . . the sunlight is the cause (sunlight explanation),

and . . . the sunlight is blocked by a blanket,

then . . . the baby should sleep longer the next morning.

Alternatively,

if . . . hunger is the cause (hunger explanation),

then . . . the baby should still wake up early.

The part of the argument *after* each *if* is the proposed explanation. For example, "The sunlight is the cause of the early waking." Or, "hunger is the cause." The part *after* the *and* can be called the **planned test** because it is a test that has yet to be carried out. In this case the planned test involves putting a blanket over the window. The part *after* each *then* is an expectation, an expected result—sometimes called a **prediction**. Expectations or predictions are statements of what *should* happen in the future—what one *should* observe in the future—*if* the proposed explanation is correct and *if* the test is carried out as planned. In other words, expectations state what should follow from the explanation and its planned test.

So now all Renee has to do to test the sunlight explanation is put a blanket over the window and compare the baby's new wake-up time with his old wake-up time. But when Renee covered the window, the baby still woke up at his usual early time. In other words, the test's **observed result** (i.e., how the test turned out) was *not* the same as the predicted result. What **conclusion** would you draw? If you conclude that the sunlight explanation is probably wrong, you are correct. The complete argument looks like this:

If . . . sunlight is the cause (sunlight explanation),

and . . . sunlight is blocked by a blanket (planned test),

then . . . the baby should sleep longer the next morning (expectation/prediction).

But . . . when the test was conducted, the baby did not sleep longer (observed result).

Therefore . . . sunlight is probably not the cause (conclusion).

Note that the last statement in the argument following the *therefore* is the conclusion. A conclusion is *not* a restatement of the observed result. Rather, a conclusion is a statement about the status of the tested explanation based on the match, or mismatch, between expected and observed results. In general, a conclusion states whether the explanation was supported or contradicted. Explanation testing may seem a bit odd in the sense that to test a proposed explanation, you have to suppose,

key ideas

planned test Imagined conditions that when carried out test a proposed explanation.

prediction A statement of an inferred (expected) future outcome of a planned test assuming that the proposed explanation being tested is correct and a test is carried out as planned; to be compared with the observed result to test the proposed explanation.

observed result The outcome of a test (evidence or data) that is compared with an expected/predicted result.

conclusion A statement or statements that summarize the extent to which a proposed explanation—a hypothesis—has been supported or contradicted by observed results.

for the time being, that it is correct. You have to do this so you can test it and perhaps find that it is *not* correct! In other words, the reasoning goes something like this: *If* the explanation is correct, *and* I do such and such, *then* I should see something happen. *But* when I did such and such, that something did not happen. *Therefore* my explanation is probably wrong. The steps in explanation generation and testing go like this:

1. A puzzling observation is made that raises a causal question.
2. One or more tentative explanations are generated.
3. A test is planned that allows one to generate an expected result—a prediction.
4. The planned test is conducted and its result is observed.
5. The observed result is then compared with the expected result.
6. A conclusion is drawn about the status of the tested explanation based on the match or mismatch of expected and observed results. A match supports the explanation. A mismatch contradicts the explanation.

How would you use these steps to test the hunger explanation and the noise explanation? See if you can generate *if/and/then* arguments to do so. Try to clearly state the proposed explanation, the planned tests, and the expected results. Imagine that when you carry out the tests, the observed results do *not* match your expected results. What conclusions would you draw? What conclusions would you draw if the observed and expected results do match?

As it turned out, when Renee tested the hunger explanation by trying to eliminate the baby's hunger with a late-night feeding, the observed result matched the expected result. Therefore, the hunger explanation was supported. Happily the little fellow slept longer the next morning. Unhappily there was a price to pay—waking up in the middle of the night for that late-night feeding!

How Are Biological Explanations Tested?

Why Do Giraffes Have Long Necks?

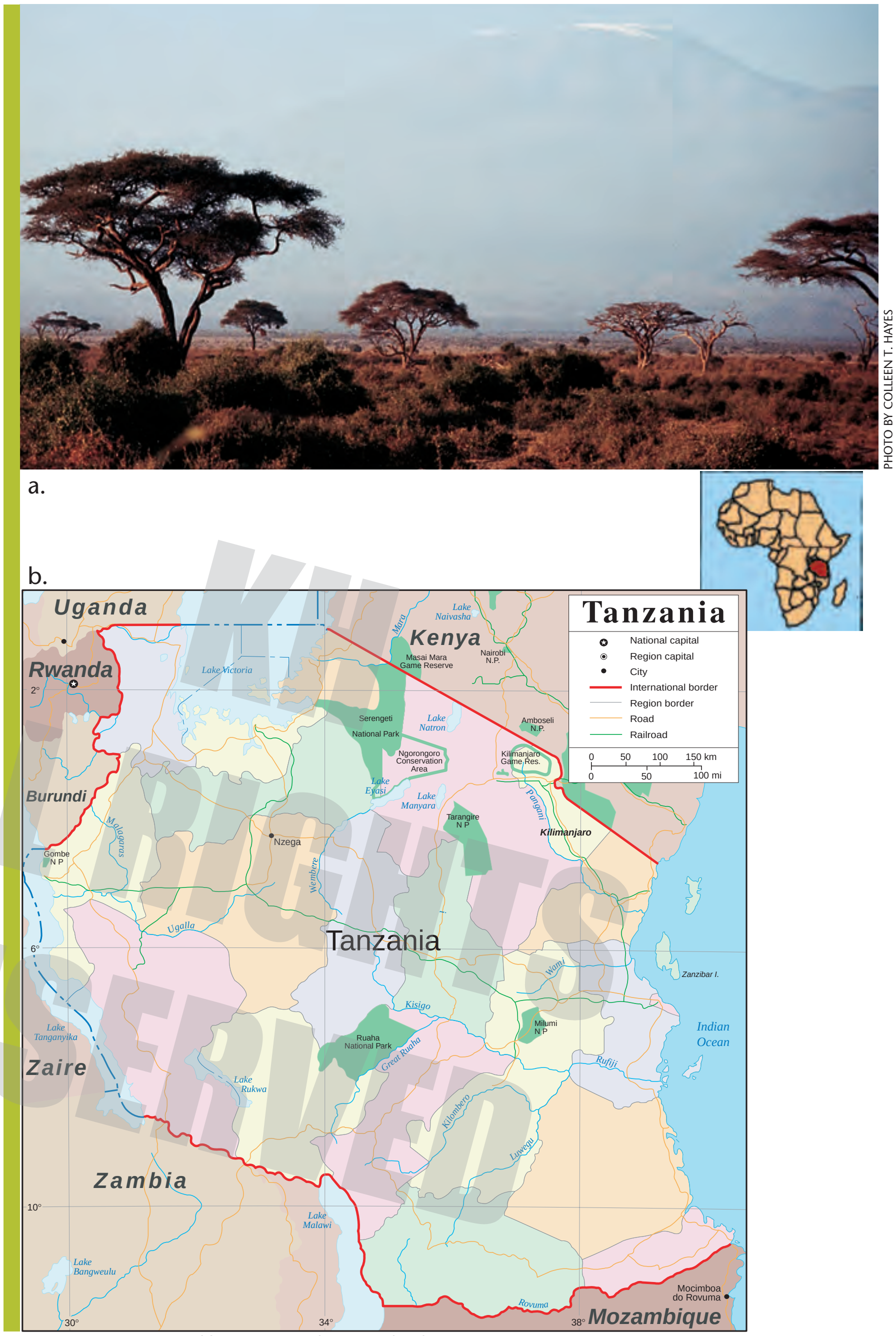
Now that we have identified the steps in generating and testing explanations in a familiar context, let's travel to the grassland biome of eastern Africa's Serengeti Plain (Figure 1.6) to see if we can find the same steps in Robert Simmons's and Lue Scheepers's research on why giraffes have such long necks. You may have read or been told that giraffes have long necks to reach leaves in tall trees. This often-repeated explanation even includes the idea that short-necked giraffes have starved, so after many generations we are now left with only long-necked giraffes. Let's call this feeding-up-high explanation. Is this explanation correct? If it were correct, where in trees would you expect to find giraffes most often feeding, particularly when food is scarce? They should be seen feeding up high don't you think? Consider the following reasoning of Simmons and Scheepers:

If . . . this feeding-up-high explanation is correct,

and . . . giraffes are surveyed to find out where they most often feed (planned test),

then . . . they should spend most of their time feeding in the upper parts of the trees, particularly during the dry season when food is scarce (expectation).

FIGURE 1.6
a) The grassland biome of the Serengeti Plain in Tanzania's Serengeti National Park. b) Map of Africa, Tanzania, and the Serengeti National Park.



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Unfortunately for the feeding-up-high explanation, recently collected data indicate that giraffes most often feed by bending their necks down (Figure 1.7). Even in the dry season, they spend nearly 40% of their time feeding at relatively low heights. Clearly this is not the expected result based on the explanation. Therefore, the result contradicts the explanation.

Can you think of an alternative explanation for the long necks? Simmons and Scheepers thought that over many generations, long necks might have been acquired for use in courtship battles between males. During such battles, two males square off and swing their necks and heads at each other. The male with the longer neck can generate more impact force, so he most often wins the battle and gets to mate with the female, while the shorter-necked loser is often left to die. Aside from these initial observations that seem to fit this alternative explanation, what other evidence could test the explanation? Simmons and Scheepers reasoned that:

If . . . the male-courtship-battle explanation is correct,

and . . . the neck lengths of males and females are compared (planned test),

then . . . males should have longer necks than females relative to their body size (expectation).

FIGURE 1.7
Feeding giraffe.

However,

if . . . the feeding-up-high explanation is correct,

then . . . both males and females should have equally long necks relative to their body size (expectation).

Simmons and Scheepers found that males do in fact have longer necks relative to their body size than females. Because this result was expected under the male-courtship-battle explanation, that explanation was supported. They also found that males have relatively larger and heavier heads than females. Although this result was not predicted, it does make sense in terms of the male-courtship-battle explanation because a heavier head, like a longer neck, increases the impact force during battle. Clearly, additional tests would be helpful. Nevertheless, the important point for now is that it appears that biologists do use the same *if/and/then* thinking pattern to test explanations, and that thinking pattern, if used, can help people get rid of some incorrect ideas.

Why Do Gazelles Leap When Being Chased?

Let's stay on the Serengeti Plain to take an even closer look at how biologists test their explanations. While watching cheetahs chase gazelles, British biologist Tim Caro noticed that running Thomson's gazelles (Figure 1.8) would often leap high in the air with their legs stiffly pointed down and their white rump fur spread. Caro's observation of this puzzling behavior, called *stotting*, led him to wonder why gazelles stott. Does stotting somehow help the gazelle escape? Caro thought that stotting was worth puzzling over because it seemed odd that gazelles would behave in a way that appeared to slow them down and make them more conspicuous and vulnerable. What explanations for stotting can you suggest?

Prior to Caro's research, another biologist published a possible explanation for stotting. He thought that stotting gives gazelles an advantage, despite appearances to the contrary, because stotting enables them to better keep an eye on the cheetah. Caro knew about this explanation but was unconvinced. Consequently, he proposed several additional explanations. One was that a gazelle stotts to warn other gazelles of danger. Another was that adult gazelles stott to draw attention from their more vulnerable offspring. Still another was that stotting signals the cheetah that it has been seen, thus tells the cheetah that the gazelle will be difficult to catch. Consequently, the cheetah should give up the chase.

FIGURE 1.8
Sometimes when running away from a cheetah the gazelle will leap up, stiffly point its legs down and spread its rump fur. This odd behavior is called stotting. Why would a gazelle stott while trying to escape?

key idea

bias A tendency or inclination in favor of one explanation or belief that prevents unprejudiced consideration of alternatives.

So Caro did not generate a single explanation. He generated several. Each of these amounts to an alternative explanation for stotting. Generating several alternatives at the outset is important because it helps one be more open-minded later on. People who fail to consider alternatives early often become **biased**. In other words, they often get stuck believing in an incorrect explanation, particularly if the explanation comes from an authority or has initial supporting evidence. Note also that Caro's alternative explanations did not come from direct observation. Rather, they came from his knowledge of similar situations. For example, Caro knew that many other animals draw attention to themselves to protect their offspring, so he suspected that gazelles might do the same.

Once Caro generated a number of alternative explanations, his next task was to test them. Caro could not test his explanations directly. Gazelles will not tell you why they stott. So he had to test them indirectly. Let's see how he did this, starting with the explanation that gazelles stott to draw attention from their offspring. Before reading on, take a few minutes and see if you can come up with a way to test this explanation. Remember, you will need a planned test and an expectation.

How Did Caro Test the Drawing-Attention Explanation?

To test the drawing-attention explanation, Caro planned a test and derived an expectation like this:

If . . . the drawing-attention explanation is correct,

and . . . we observe gazelles that have no offspring while being chased (planned test),

then . . . they should not stott (expectation). These gazelles should not stott because they have no offspring to draw attention from.

Now that Caro had an expectation—a prediction, his next step was to conduct the planned test and observe what happened. When Caro later observed gazelles without offspring being chased, he saw that they did stott. Therefore, Caro concluded that the drawing-attention explanation was not supported. Do you agree?

Just like in the case of Renee's baby, Caro's test made use of *if/and/then* reasoning that starts by supposing that the proposed explanation is correct. This supposition along with his planned test allowed Caro to generate an expectation, *before* he actually conducted his test and *before* he gathered his evidence. Caro then conducted the planned test and observed its result. Because his expected and observed results were *not* the same, Caro concluded that the drawing-attention explanation was probably wrong.

How Did Caro Test the Signaling Explanation?

Having rejected the drawing-attention explanation, Caro next tested the idea that stotting signals the cheetah that it has been spotted, hence the gazelle will be difficult to catch. How can we test this idea? Caro reasoned that:

If . . . the signaling explanation is correct,

and . . . one looks to see where the stotting gazelles point their rumps (planned test),

then . . . the gazelles should point their rumps at the cheetahs (expectation). Presumably, pointing their rumps at the cheetahs would be the best way to send the signal.

Sure enough, when Caro watched closely, he saw that the stotting gazelles pointed their rumps directly at the cheetahs and not at other gazelles. Therefore, he found support for the signaling explanation. Should Caro stop here? Although support had been found, Caro believed that the signaling explanation should be tested further because other possibilities remained. After all, the fact that stotting gazelles point their rumps at cheetahs could be explained simply by the fact that they are running from the cheetahs. So their rumps should quite naturally be pointed at the cheetahs!

What other way might we test the signaling explanation? Let's examine the relationship, if any, between stotting and getting caught. Consider this argument: *If* stotting signals the cheetah that it has been spotted, and hence the gazelle will be difficult to catch, *and* several chases are observed, some in which stotting takes place and some in which it doesn't, *then* stotting gazelles should get caught less often than non-stotting gazelles. Presumably the stotting gazelles won't get caught as often because the cheetahs have received the message that they have been spotted. So they will give up the chase.

Based on this argument, what data should Caro record while watching the chases? If you think he needs to record whether or not each gazelle stotted, and whether or not it got caught, you are correct. However, before considering Caro's results, look at Table 1.1. The table has two rows, two columns, and four boxes. The boxes are labeled a, b, c, and d. Box a represents the number of stotting gazelles that were caught. Box b represents the number of stotting gazelles that were *not* caught. Box c represents the number of *non-stotting* gazelles that were caught. And box d represents the number of *non-stotting* gazelles that were *not* caught. Suppose the signaling explanation is correct. In which of these boxes would you expect to find large numbers or small numbers? What would you expect the numbers to look like if the explanation is wrong—that is, if stotting does not help the gazelles escape?

table 1.1 Evidence needed to test the signaling explanation.

		Caught: yes	Caught: no
Stott	yes	a	b
	no	c	d

Compare your expected numbers with Caro's numbers (his observed results) shown in Table 1.2. Do these numbers support the signaling explanation? If the explanation is correct, we would expect that the non-stotting gazelles would be more likely to get caught than the stotting gazelles (see Box 1.2). Did this happen? Of the 5 + 19 = 24 non-stotting gazelles, 5 of them got caught (5/24 = 21%). Of the 0 + 7 = 7 stotting gazelles, none got caught (0%). So it looks like the non-stotting gazelles got caught about 21% of the time, while the stotting gazelles got caught 0% of the time. The stotters always got away! Stotting seems to help. Therefore, the signaling explanation has been supported.

table 1.2 Caro's observed results used to test the signaling explanation. Does the evidence support the explanation?

		Caught: yes	Caught: no
Stott	yes	0	7
	no	5	19

This test involves the establishment of a co-relationship or **correlation** between the **values** of two **variables.** In this case, the "amount of stotting" variable has values of "stotted" or "did not stott." The "caught" variable has values of "caught" or "was not caught." This type of evidence is referred to as **correlational evidence**. When using correlational evidence, the investigator tries to find out whether or not the values of the two variables are "linked" (i.e., are correlated). Correlational evidence can be a useful way to test explanations. Suppose, for example, someone proposes that smoking causes lung cancer in humans. What correlational evidence could you use to test this explanation?

key ideas

correlation Mutual relation of two or more things, parts, or variables.
value A specific quantity, magnitude, number or rank of a variable or system of classification. For example, among people, values of the gender variable are male and female; values for the weight variable are 100 pounds, 150 pounds and so on.
variable A characteristic (property, trait) with values (e.g., numbers, colors, sizes) that differ among objects, events, or situations in a group. For example, in a group of students, their heights differ; thus "height" is a variable. A variable is the opposite of a **constant**.
constant A characteristic (property, trait) with values (e.g., numbers, colors, sizes) that do not differ among objects, events, or situations in a group. For example, in a group of students, all have one nose; thus "number of noses" is a constant. A constant is the opposite of a variable.
correlational evidence Evidence that tests a possible explanation by determining the extent to which the values of two or more variables that have been predicted to be correlated, are in fact correlated.
experiment A manipulation of nature designed to test a hypothesis.
experimental evidence Evidence derived from an experiment that tests an explanation.

Correlational evidence can test explanations. But finding a link, a correlation, between two variables in the absence of a prior explanation does not tell us which variable is the cause and which is the effect, if indeed a causal relationship exists. Fortunately, as we saw while trying to find out why Renee's baby was waking up so early, a second type of evidence can test explanations. As you recall, Renee tested the sunlight explanation by hanging a blanket over the window. In other words, she "manipulated" the situation to eliminate the early morning sunshine. Tests that involve manipulating nature are called **experiments**, and experiments produce what is called **experimental evidence**. Experimental evidence has an advantage over correlational evidence because it can more clearly establish the link between cause and effect. The next chapter will explore in detail how experiments test explanations.

box 1.2 Connecting Science and Mathematics: Probability and Random Sampling

What are your chances of winning a $50,000 jackpot in the lottery? What are your chances of being struck by an automobile while crossing the street? What are your chances of living to be 100 years old? Do frogs with spots have a better chance of survival than frogs with no spots? Does a farmer have a better chance of raising a good corn crop if he sprays with insecticide?

The notion of chance (i.e., probability) is fundamentally embedded in every part of our lives as well as those of every living organism. Understanding probability is, therefore, fundamental to understanding life and the world in which we live. The following examples and questions are provided to help you better understand how probabilities are estimated and the role they play in exploring nature.

What Are the Chances of Picking the Yellow Tennis Ball?

Imagine a girl walking down a bumpy dirt road bouncing two tennis balls, a white one and a yellow one. Each time she bounces the balls, the yellow ball bounces higher than the white ball. As you watch, a second girl carrying a tennis racket runs up to the first girl and says, "Hey, Sis, give back my yellow tennis ball. It's time for my tennis lesson." At hearing this, the first girl replies, "No. I want it. You can have the white ball." The second girl exclaims, "I don't want the white ball. It doesn't bounce worth beans." To this the first girl says, "I'll tell you what. I'll hold both balls behind my back—one in each hand. If you guess which hand has the yellow ball, you can have it." The second girl replies, "OK, but hurry up. I'm late. I'll pick the left hand."

Question: What are the second girl's chances of guessing the hand with the yellow ball? The answer, of course, is that the chances are 1 out of 2, one-half, 1 to 1, 50–50, or 50%, depending on how you say it. In this situation there are two possible picks the second girl can make—the right hand or the left hand. These picks are called *possible events*. Picking the yellow ball is the event that the second girl wants—the *desired event*. This desired event is one of the two possible events, so the second girl's chances (probability) of getting what she wants is 1 out of 2, which can be written as 1/2:

$$\frac{1(\text{event of picking yellow})}{1(\text{event of picking yellow}) + 1(\text{event of picking white})} = 1/2$$

The other answers—1 to 1, 50–50, or 50%—also describe the probability. One to one means that for every 1 event that is correct (picking the hand with the yellow ball) there is 1 event that is not correct (picking the hand with the white ball). Fifty-fifty means that if you guessed 100 times, half of your answers (50) would be correct and half (50) would be incorrect. Fifty percent means that if you guessed 100 times, you would guess correctly 50 times (50 out of 100 = 50/100 = 50%). So, the probability (the chances) of the second girl picking the yellow tennis ball is 1/2 stated as a fraction or 50% stated as a percent.

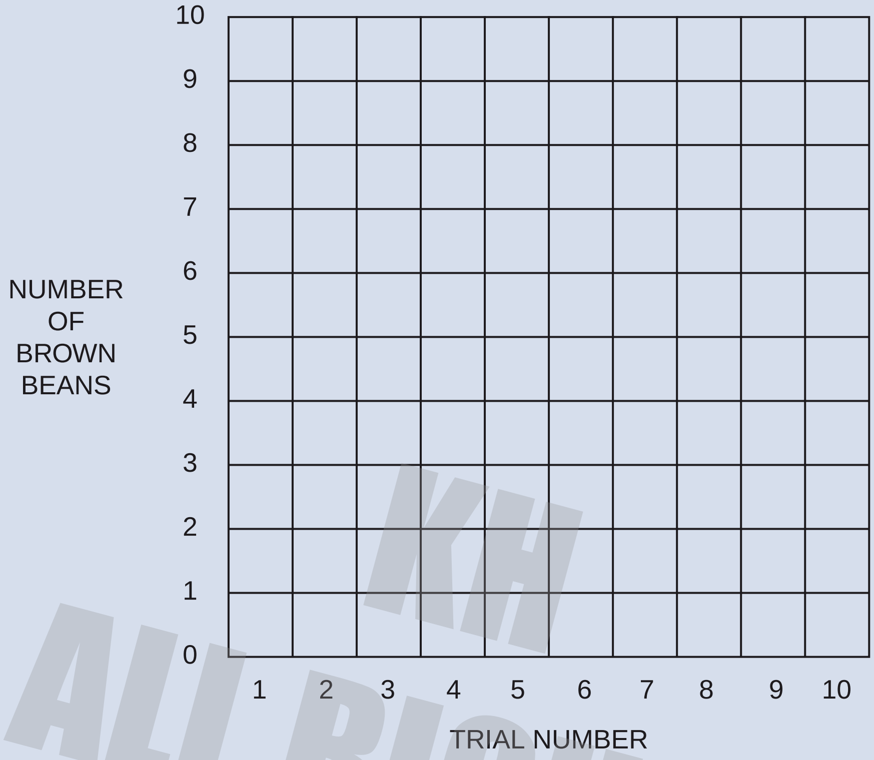
What Does 50% Really Mean?

But what does 50% really mean? Does it mean that if the second girl guessed which hand held the yellow ball 100 times she would guess correctly *exactly* 50 times? Let's see what this does mean through an activity.

Find a paper sack and some brown and white beans of the same size and shape. Put 50 brown beans and 50 white beans in the sack. Now close the sack and shake it up. Without looking into the sack, pick out 10 beans. How many of these beans are brown? Plot this number on the following graph in the column for trial number 1.

Now put the 10 beans back into the sack and shake the sack again. Pick out another 10 beans. How many of these beans are brown? Plot this number on the graph in the column for trial number 2. Again put the 10 beans back into the sack and again shake the sack. Repeat this shaking, picking, and plotting procedure 8 more times.

box 1.2 *(continued)*



Look at your graph. Does it appear as though on *average* 5 out of every 10 beans are brown? Is this the same as saying that on average 1 out of every 2 beans are brown? Does 5/10 = 1/2 = 50/100 = 50%? Why did you not pick out 5 brown beans and 5 white beans in each trial? What was the total number of brown beans you picked out for all ten trials? Why is this number close to 50, but not exactly 50?

In the above activity, the 100 beans are called a *population*. You obtained 10 *samples* of the bean population. They were selected "at random" in the sense that any one bean or any color of bean was just as likely to be picked as any other. Thus even if you did not know the number of brown beans in the bean population, you could use your random (representative) samples to estimate (guess) the fraction of brown beans in the entire bean population. Of course, we know that the brown fraction is 50 out of 100 = 50%. Therefore, in this population the probability of a bean being brown is 50%. But if we did not know this, the samples would provide an estimate of this probability. As you can see from the activity, sample estimates typically contain some error. When sampling a population, the idea is to make the error as small as possible by sampling several times or by obtaining as large a sample as possible without going to too much trouble or expense.

The probability of any desired event(s) is given as follows:

$$\text{Probability} = \frac{\text{Number of desired event(s)}}{\text{Total number of possible events}}$$

Multiplying this fraction by 100 gives the probability expressed as a percent.

QUESTIONS

1. If you flip a coin, what is the probability it will come up heads?
2. When you roll a die, what is the probability you will roll a 6?

(continued)

box 1.2 (continued)

3. Suppose 5 real diamonds and 20 fake diamonds are put into a sack. What are your chances of reaching in the sack and pulling out a real diamond on the first try?
4. A farmer collects 25 mice from a corner of a field and finds that 20 of them are spotted and 5 are entirely brown. a) How many mice are in the farmer's sample? b) What fraction of the mouse sample is spotted? c) What percentage of the mouse sample is non-spotted? d) Suppose the farmer captures one more mouse. What is the probability that the mouse will be spotted?
5. In a small town in upstate New York, 75 people were given the swine flu vaccination last winter. Five of those 75 people developed muscular paralysis within two weeks of receiving the vaccine. a) What fraction of the people developed paralysis? b) Suppose you were to go to that town and were vaccinated from the same batch of vaccine. What would you estimate your chances are of developing paralysis? Explain.
6. On the first day of class in a college biology course for nursing majors, 23 out of the 28 students were females. a) What percentage of the biology course is female? b) On the second day of class a new student enrolled. What is the probability that this student is a male? c) Does this mean that only about 18% of the college's student population is male? Explain.
7. What is the probability of finding a needle in a 5-foot tall haystack within 1 hour? Explain.

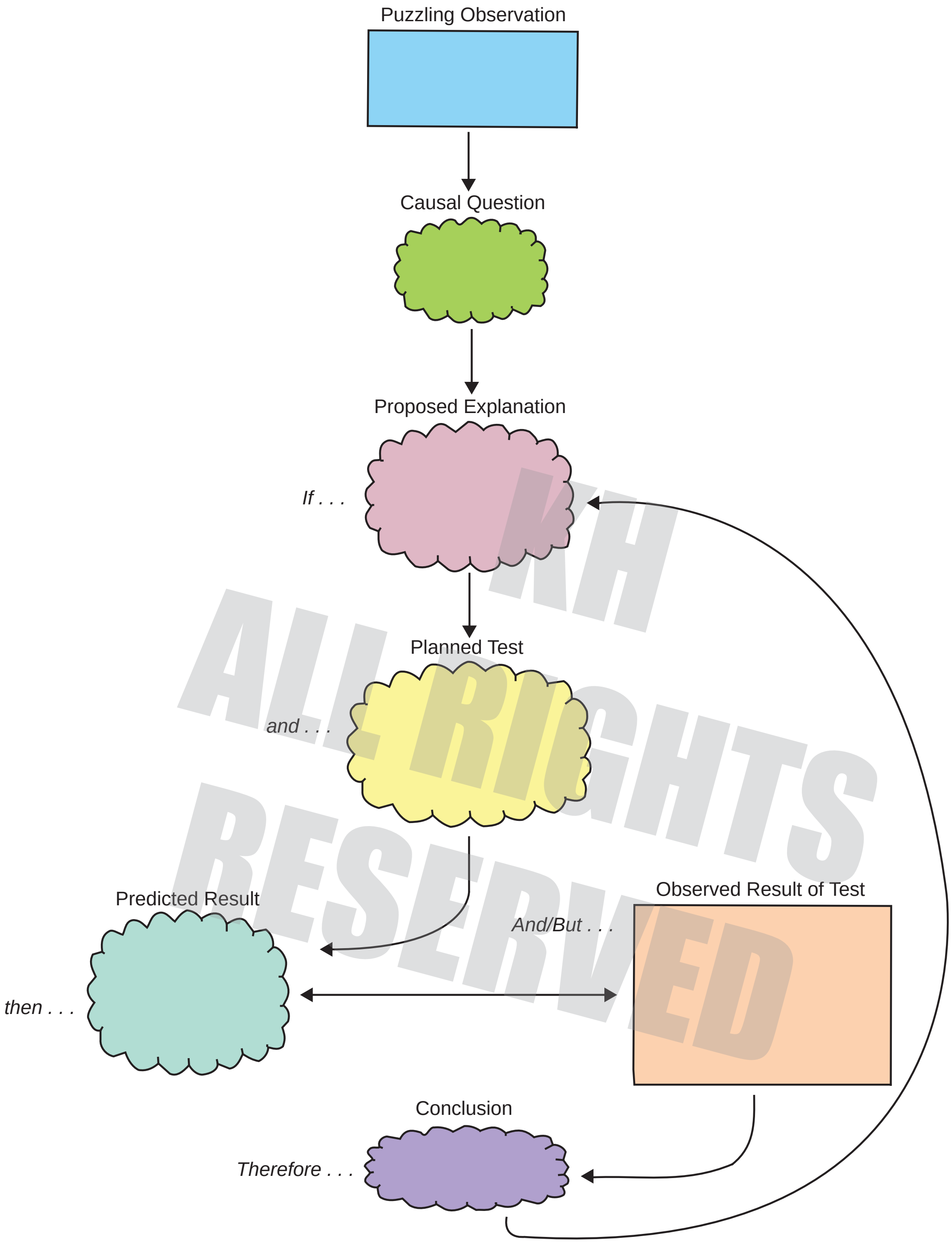
Answers appear on page 697.

Summary

1. The main goal of science is to accurately describe and explain nature by raising and answering descriptive and causal questions. Science consists of methods of description and explanation plus the descriptions and explanations that have been obtained. Biology is the science of living things and their interactions with each other and the physical world.
2. The generation and test of alternative explanations is basic to doing science. The initial generation of several alternative explanations encourages an unbiased test because a researcher is less likely to be committed to any specific explanation. Explanations are tested by use of an *if/and/then* reasoning pattern. A test begins by supposing that the explanation is true and by planning some test that allows the generation (via deduction) of one or more expected results (predictions). Data (observed results) are then gathered and compared with the expectations. A good match provides support for the explanation, while a poor match contradicts the explanation and may lead to its rejection.
3. Explanations can be tested using correlational or experimental evidence. Use of correlational evidence relies on determination of the extent to which the values of two or more variables vary together. Use of experimental evidence relies on the manipulation of possible causal variables.

Study Guide

1. You should be able to define and provide an example of each of the following terms: bias, biome, biosphere, causal question, correlation, correlational evidence, conclusion, constant, deduction, descriptive question, expectation, experiment, experimental evidence, observed result, planned test, prediction, puzzling observation, value, variable.
2. During the next day or two, note several puzzling objects, events, or situations that raise causal questions. For example, suppose while on the way to class you notice an automobile accident and ask: What caused the accident? Or perhaps you notice a spot of yellow grass in the middle of someone's green lawn and ask: What caused the yellow spot? Make a list of five such causal questions. Generate two alternative explanations to answer it. How could your proposed explanations be tested? Use the pattern of *if/and/then* reasoning to generate predictions (expected results) based on your explanations and some imagined test conditions.
3. Generate a list of five descriptive questions. For example, some descriptive questions regarding the auto accident might be: Was anyone hurt? How many people were in the cars? How fast were the cars going?
4. In general, how does a description of an event differ from an explanation? Provide an example.
5. Check the newspaper during the next few days for at least two articles that discuss scientific studies. Identify the causal questions raised. What explanations were generated? What sort of evidence was used to test the explanations? Were they supported or not supported? Were you convinced by the arguments and evidence? Explain. (Note: Newspapers often use the term "theory" for a proposed explanation.)
6. Given a group of students, name five ways in which the individuals in the group are likely to vary. Name two values for each of the named variables.
7. Fill in the boxes and "clouds" in the figure on the following page to construct a complete argument regarding Renee's test of the sunlight explanation as discussed in this chapter. The boxes in the figure represent observations (i.e., observation of the puzzling phenomenon and observation of the test result) while the "clouds" represent unobservable elements of the explanation testing process (e.g., the proposed explanation, the planned test). Start by writing "The baby is waking up early" in the top box. The causal question can be stated like this: "Why is the baby waking up early?" Write this statement in the first "cloud." Now write the sunlight explanation in the second "cloud" (i.e., The sunlight is the cause of the baby waking up early.). Now complete the rest of the figure.


Puzzling Observation
Causal Question
Proposed Explanation
If . . .
Planned Test
and . . .
Predicted Result
then . . .
Observed Result of Test
And/But . . .
Conclusion
Therefore . . .
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