Chapter 1

The Science of Biology

Introduction

Science is the attempt of people to understand the objects and events they experience in nature. People develop an understanding about things they experience by asking questions and by finding answers. *What is life? What causes animals to die? What happens to frogs in the winter when their pond is frozen over? Why do so many different kinds of plants and animals exist?* In attempting to find answers to such questions, a person is doing science. Because all of these questions involve living things, finding answers to such questions involves doing biology—the science of life.

A Theory of Knowledge Acquisition

How does someone "do" biology? How does someone answer questions about life? How does someone answer any question? Consider the following:

A few years ago, the behavior of the 1-year-old son of the author raised a question. The boy was waking at about five o'clock each morning. As far as his parents were concerned, this was too early. Why was he waking up so early? The problem was to discover the cause so that something could be done to get him to sleep longer.

Because the boy's awakening occurred in the summer when the sun was streaming through the window very early, his parents thought that perhaps the light was awakening him. This is a *hypothesis.* A hypothesis is a tentative explanation for some experience. It is a possible answer to the question raised. In this case, it is a tentative answer to the question, *What caused the child to wake up so early?* A second hypothesis was that the child was hungry and his hunger had awakened him. Although other hypotheses could be suggested, these seemed to the parents the most likely. Generating hypotheses is an important first step in answering a question. The second step involves testing the hypotheses to find out which one is best. How is this done?

To test any hypothesis, one must first determine what would happen if the hypothesis is right. In other words, if the hypothesis is correct, then what do you predict will happen under certain conditions? Testing all hypotheses requires thinking that takes this *If . . . and . . . then* form; this thinking is referred to as a process of *deduction.* The result of making a deduction is often a *prediction.* A prediction is simply what you would expect the experiment to show if the hypothesis is correct. The *If . . . and . . . then* thinking that is used to determine correctness of the present hypothesis looks like this:

Hypothesis: *If*...the sunlight coming through the window was awakening the child.
Experiment: *and*...the sunlight is blocked with a heavy cover over the window,
Prediction: *then*...he will awaken later.

On the other hand...

Hypothesis: *If*...his hunger was awakening him.
Experiment: *and*...he is fed an additional bottle of milk at midnight,
Prediction: *then*...he will awaken later.

The result of making a deduction is a *prediction.* A prediction is simply what you would expect the experiment to show if the hypothesis is correct.

What remains to be done to test the hypothesis is to compare the prediction with what in fact happens when you try the experiment. If what is predicted actually happens, then you have supported your hypothesis. (You place a heavy cover over the window, and the child awakens later.) If what happens is different from the prediction, then the hypothesis has not been supported. (The child is fed an additional bottle of milk at midnight, but he still awakens at 5:00 a.m.) If what is predicted does not happen, then you must conclude that either something was wrong with your hypothesis or something was wrong with the way you did your experiment. This last phase of trying to answer a question is sometimes called the *test phase* because the purpose is to test (either support or contradict) the hypotheses that have been advanced.

Trying Your Mind at Deductive Reasoning

To provide you with an opportunity to use the deductive reasoning process in simple situations, three puzzles are shown in Figures 1-1 to 1-3. The puzzles involve creatures called Skints, Mellinarks, and Quarks. Because the procedure for solving each puzzle is the same, only the procedure for the first puzzle will be explained. The first row of creatures in Figure 1-1 are all Skints because they have something in common. None of the figures in the second row are Skints because they do not have that something. Based on this information, your task is to figure out which of the figures in the third row are Skints. Once you think you have solved the Skints puzzle, go on to the other puzzles.

When you are finished, compare your answers with those of your classmates; more importantly, compare the reasoning patterns you used to arrive at these answers. Make sure to identify the ideas and the deductions that were generated. Name some of the ideas that were rejected, and write a sentence or two summarizing the reasoning that led to their rejection. For example, the following argument states why the idea that "Mellinarks are creatures defined solely by the presence of a tail" is insufficient and must be modified or rejected:

Idea:	*If*...Mellinarks are creatures defined solely by the presence of a tail
Experiment:	*and*... I examine the non-Mellinarks in row two,
Prediction:	*then*... none of the non-Mellinarks in row two should have a tail.
Result:	*But*...the first, third, fourth, and sixth creatures in row two have tails.
Conclusion:	*Therefore*...the idea that Mellinarks are creatures defined solely by the presence of a tail must be rejected: I need to generate another idea.

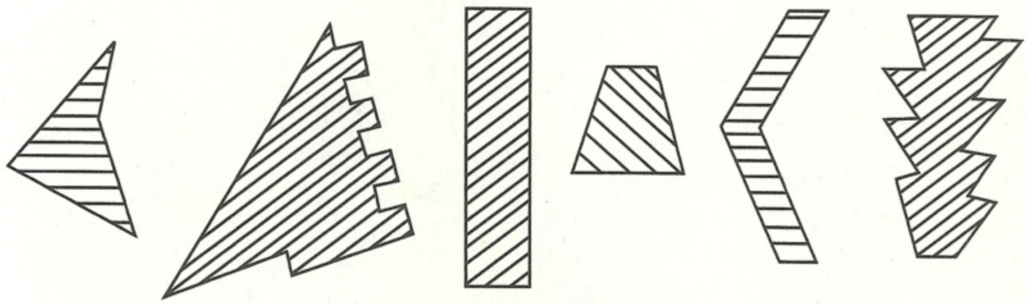
The Nature of Hypotheses in Science

Because hypotheses play such a crucial role in science, obtaining a clear understanding of that role is absolutely essential. Hypotheses are not merely educated guesses. Generating hypotheses does require background knowledge, and it does require an element of guessing; but not all educated guesses are hypotheses.

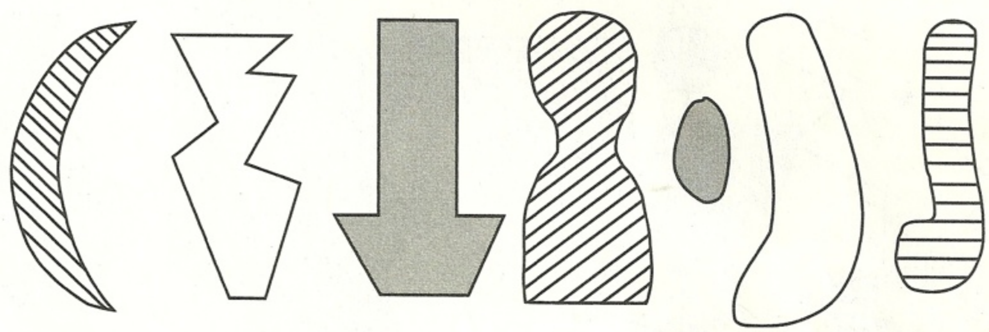
Suppose, for example, that you taste a green apple and discover it sour. After tasting a second, third, and fourth green apple, you also find them sour. From this "education" you "guess" that all green apples are sour, and on the basis of this you predict that the next green apple you taste will also be sour. Does your educated guess that "all green apples are sour" constitute a hypothesis? I think not. It is merely a

SKINTS

All of these are *Skints.*



None of these is a *Skint.*



Which of these are *Skints*?

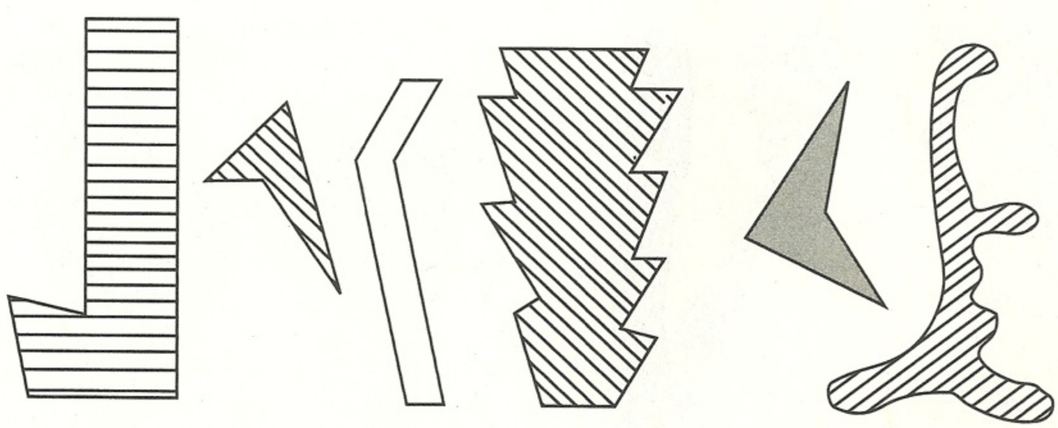
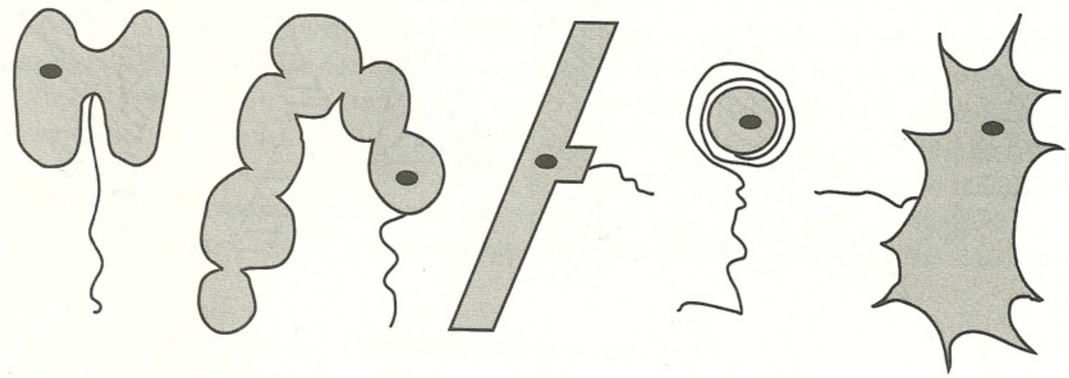


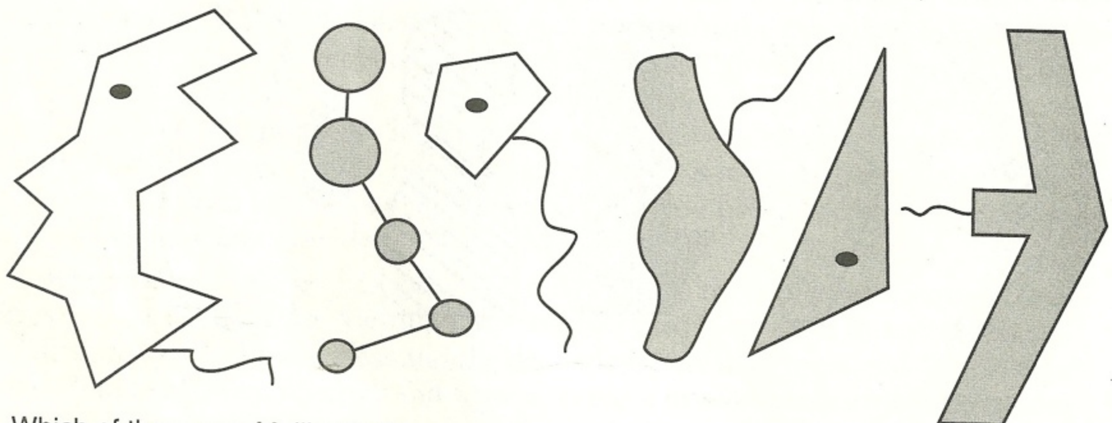
Figure 1-1.

MELLINARKS

All of these are *Mellinarks.*



None of these is a *Mellinark.*



Which of these are *Mellinarks?*

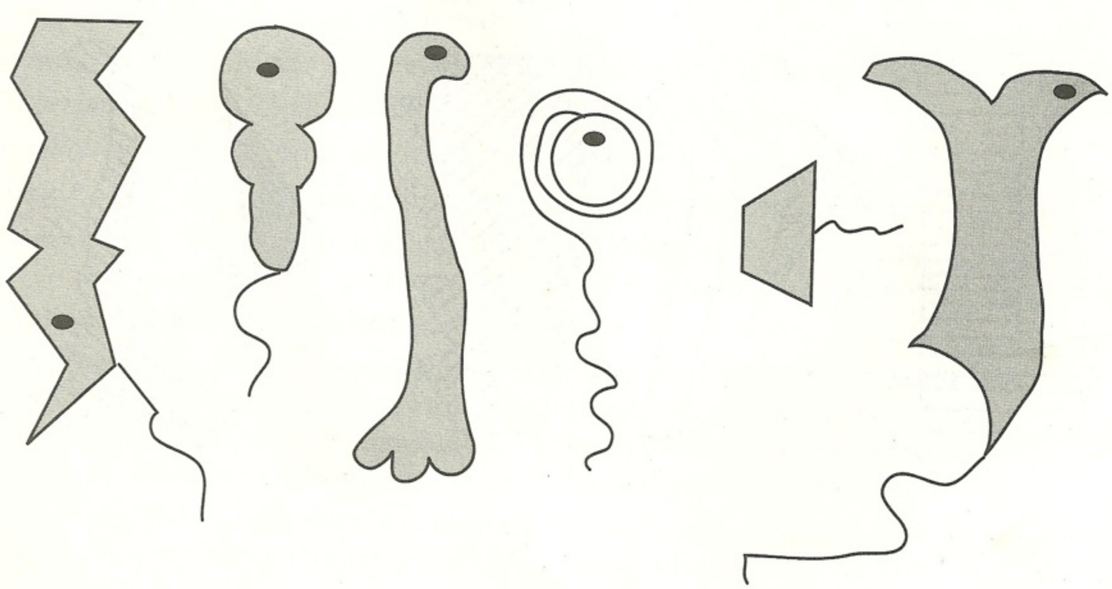
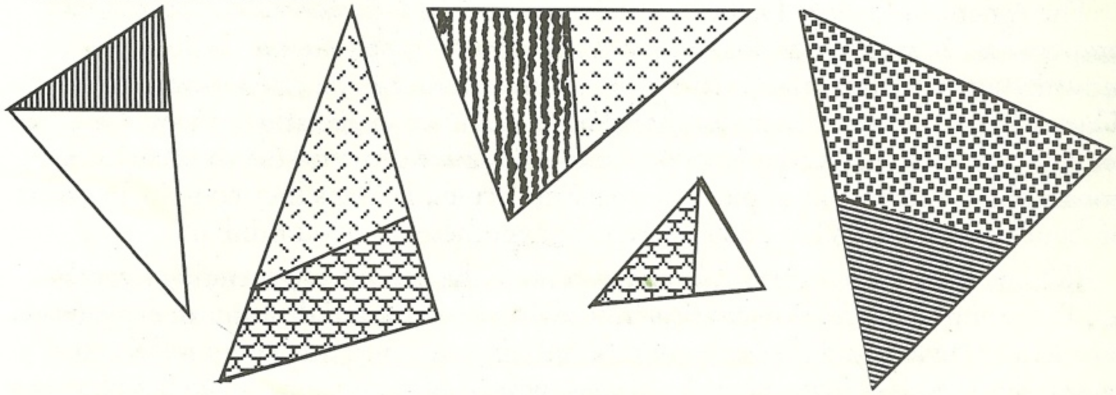


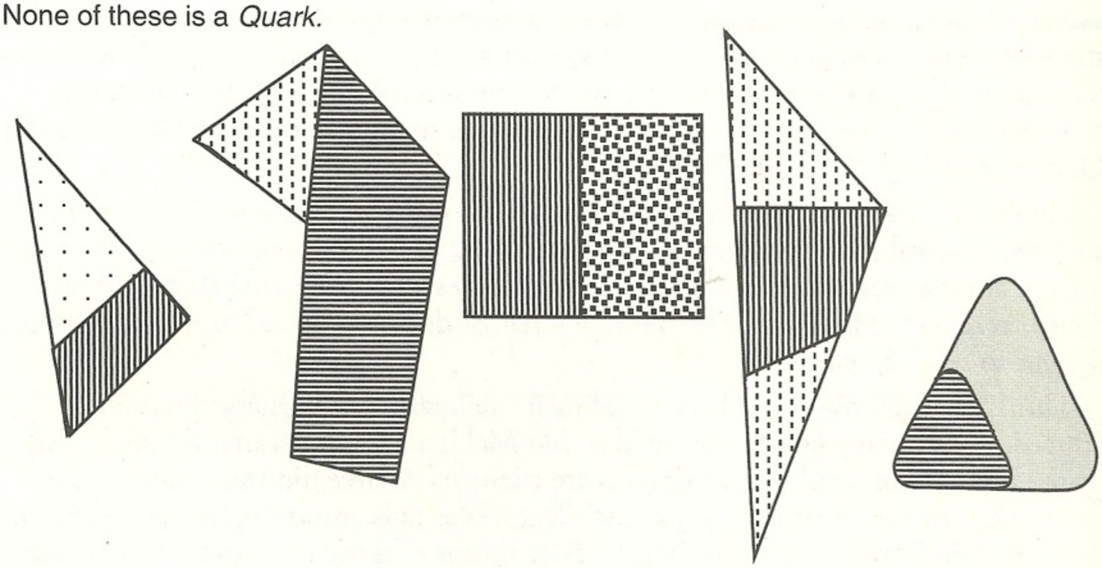
Figure 1-2.

QUARKS

All of these are *Quarks.*



None of these is a *Quark.*



Which of these are *Quarks?*

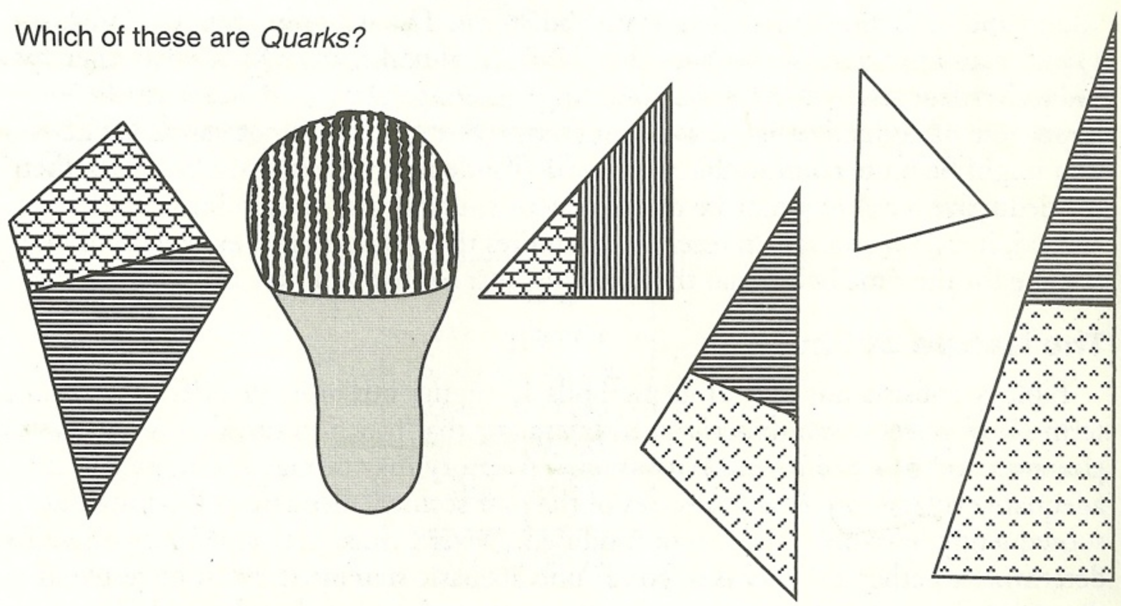


Figure 1-3.

generalization (an induction) based on limited experience. Is the educated guess that "the next green apple will be sour" a hypothesis? Again, I think not. Instead, it is better referred to as a *prediction.*

The American College Dictionary defines the word *hypothesis* as "a proposition proposed as an explanation for some specific group of phenomena." Further, the same dictionary defines the word *explain* as "to make clear the cause or reason of." Thus, a hypothesis is a statement that is proposed as an explanation, a tentative cause for some specific observation—in this case, a tentative cause for the sourness of the green apples. Perhaps the apples lack sugar molecules. Perhaps they contain an excess of "sour" molecules. What other alternative hypotheses can you think of?

Philosophers use the term *abduction* to refer to the process of generating hypotheses; for example, "Abduction consists in studying the facts and devising an explanation for them." Obviously, doing so requires some education and some guessing about causes, the guesses coming from the creative process of sensing ways in which the current situation is somehow similar (analogous) to other known situations and using this similarity as a source of hypotheses in the present situation. Perhaps you know that sugar molecules make candies and cookies sweet, so it seems reasonable to borrow this idea and use it to explain the lack of sweetness in the green apples. Thus, the statement "Green apples are sour because they lack sugar molecules" is a hypothesis. Of course, it may or may not be "true."

Finally, good scientists do not merely consider one possible cause, but as many alternative possibilities as they can think of. Then, they set out to devise ways of testing the alternatives by deducing their consequences and comparing these with evidence, as depicted in Figure 1-4. Thus, a scientist does not try to "prove" a hypothesis, but to see *if* it works.

Think back to how you solved the Skints, Mellinarks, and Quarks puzzles. Suppose you initially generated the idea that Mellinarks are creatures defined solely by the presence of a tail or that Quarks are triangles. Where did these ideas come from? The answer, of course, is that such features as tails and triangles are present in the creatures shown in row one. This answer means that the ideas came from observation and induction rather than from abduction. The reasoning that was used to generate and test your ideas about the Skints, Mellinarks, and Quarks was, therefore, inductive-deductive; whereas the reasoning used to generate and test scientific hypotheses is abductive-deductive (sometimes referred to as hypothetical-deductive). You might be quite comfortable with inductive-deductive reasoning, and hypothetical-deductive reasoning may be rather new to you and may seem a bit strange. Indeed, it *is* a bit strange. In essence, it requires that you generate explanations and assume for the time being that they are true, just so that you may find them false!

The Nature of Theories

Biology consists not only of its methods of inquiry but of its theories as well. The term *theory* refers to combinations of statements that function together to explain a phenomenon or set of related phenomena. A theory may or may not represent an adequate explanation. Many theories of the past seemed adequate at the time but subsequently have been rejected or modified. Nevertheless, they remain theories. To determine whether a theory is a "good" one, its basic statements must be tested as discussed above. It is by no means an understatement to say that the central purpose of modern biology is to generate and test comprehensive theories about life.

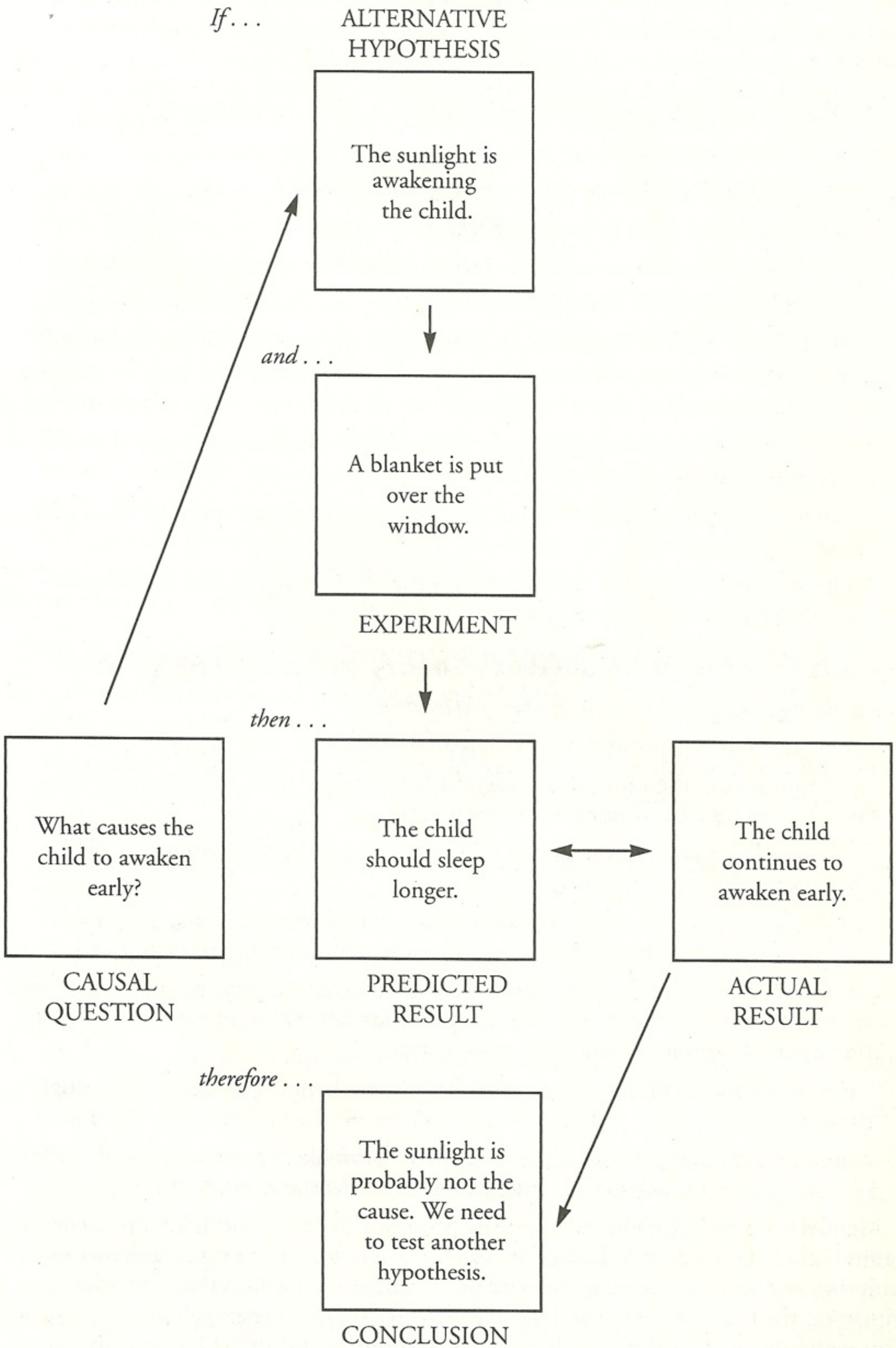


Figure 1-4. The pattern of hypothetical-deductive reasoning used to test the hypothesis that sunlight is awakening the child.

Perhaps the best way to provide you with a sense of how the term *theory* is used is to offer a few examples. Below are the major statements (sometimes referred to as postulates, basic premises, or fundamental assumptions) of two major theories in biology.

Postulates of Gregor Mendel's Theory of Inheritance

(To explain how characteristics are passed from parent to offspring)

1. Inherited characteristics are determined by particles called *factors.*
2. Factors are passed from parent to offspring.
3. Individuals have at least one pair of factors for each characteristic in each body cell except the gametes (egg and sperm cells).
4. During gamete formation, paired factors separate. A gamete receives one factor of each pair.
5. The chances are equal that a gamete will receive either one of the factors of a pair.
6. In the case of two or more pairs of factors, the factors of each pair assort to the gametes independently.
7. Factors of a pair that are separated in the gametes recombine randomly during fertilization.
8. Sometimes one factor of a pair dominates the other factor so that it alone controls the characteristic (dominant).

Postulates of Charles Darwin's Theory of Natural Selection

(To explain how organisms adapt to their environments)

1. Populations of organisms have the potential to increase very rapidly.
2. In the short run, the number of individuals in a population remains fairly constant because the conditions of life are limited.
3. Individuals in a population are not all the same; they have variations (variable characteristics).
4. A struggle for survival exists, so individuals having favorable characteristics will survive and produce more offspring than those with unfavorable characteristics.
5. Some of the characteristics responsible for differential survival and reproduction are passed from parent to offspring (i.e., they are heritable). Hence, natural selection exists for certain favorable characteristics.
6. The environments of many organisms have been changing throughout geologic time.
7. Natural selection causes the accumulation of favorable characteristics and the loss of unfavorable characteristics to the extent that new species may arise.

Mendel's theory of inheritance was first proposed in 1866, and Darwin's theory of natural selection was first published in 1858. Although research on inheritance and evolution continues to this day, most of the postulates of both of these theories have withstood the test of time as the available evidence supports their validity. Consequently, the theories are called *embedded theories,* and they play very important roles in modern biological thought. Although the postulates of these and other embedded theories may take on the status of "fact," the possibility of coming up with a better theory or with evidence that contradicts one or more of the postulates always remains. Therefore, absolute certainty is not attainable.

Theories play a central role in science, but their role is not limited to the sciences. Theories also play a central role in virtually all areas of life, including how countries govern themselves. Consider, for example, the postulates of the political theory of government put forth in 1776 in the Declaration of Independence:

1. All men are created equal.
2. All men are endowed by their Creator with certain inalienable rights, among them life, liberty, and the pursuit of happiness.
3. To secure these rights, governments are instituted.
4. Governments derive their just powers from the consent of the governed.
5. Whenever any form of government becomes destructive of these ends, it is the right and duty of the people to alter or abolish it and to institute a new government.
6. The new government should be based on the principles stated and its powers organized in such form as to most likely effect the safety, happiness, and future security of the people.

Although this book will restrict itself to the discussion of biological theories, keep in mind that theories exist in all fields and that your understanding and success will be enhanced if you are able to identify and test the key postulates of these theories.

Basic Postulates of the Theory of Knowledge Acquisition

1. Causal questions about nature are tentatively answered by generating alternative explanations, using a process called *abduction.*
2. Alternative explanations may consist of single statements attempting to explain a single phenomenon or a group of closely related phenomena, in which case the explanations are referred to as *hypotheses.*
3. Alternative explanations may consist of several statements, called *postulates,* that taken together attempt to explain a broad class of phenomena, in which case the explanations are referred to as *theories.*
4. Alternative explanations are tested by experiments that allow the deduction of specific experimental predictions from the proposed explanatory statement or statements.
5. Predictions are then compared with experimental results (evidence). If the results are as predicted, the statement that led to the prediction is supported. If the results are not as predicted, the statement is weakened.
6. Hypotheses and theories may be satisfactory or unsatisfactory explanations, depending on the evidence that has been gathered in their favor or disfavor and the extent to which they fit with other established hypotheses or theories.
7. When the postulates of a particular theory are continually supported by evidence, the theory itself may become widely accepted and become an embedded theory.
8. Because the possibility of generating a better theory and/or generating contradictory evidence always remains, no theory, embedded or otherwise, can be considered correct in any absolute sense.

Do not be overly concerned if you do not fully understand many of these points. They are being presented at the outset of the course merely to provide you with a general sense of what this course is going to be about. Although much of this material may be somewhat confusing now, it is hoped that by the end of the year it will make perfect sense.

Questions for Reflection

1. During the next day or so, be on the lookout for objects, events, or situations that raise questions about causes. For example, on the way to school you might observe a spot of yellow grass in the middle of your neighbor's green lawn and ask, *What caused the yellow spot?* Or, you might be watching television only to have the picture flicker off, and so you ask, *Why did the picture go off?* Make a list of five such causal questions.
2. For one of the five causal questions you listed for question 1, propose two alternative answers (hypotheses).
3. Use the *If...and...then* reasoning pattern to generate a prediction to test one or both of the alternatives you proposed in question 2.