CHAPTER 1

SCIENCE IS AN ELF

Evidence, Logic, and Falsification as the criterion for scientific decision-making. A question beginning with the interrogative "Why" is not a good scientific question. The art of structuring a question so that it can be tested. The controlled experiment

WHY BOTHER WITH SCIENCE?

This book has several goals. In the first instance it is about how scientists evaluate information and draw conclusions. Understanding this process is a requirement for modern life and it is an important aspect of every part of our lives. Thomas Jefferson is reputed to have said, "An informed citizenry is the bulwark of a democracy…" Today, to be a participant in the community of "informed citizenry," one must be able to interpret scientific information. It is difficult if not impossible to function effectively in society without some knowledge of the scientific process.

Every day the newspaper or television brings forth a large issue of some concern to each of us, but how prepared are you, really, to evaluate the arguments that global warming is real, will affect your way of life, will threaten coastlines, is responsible for severe hurricanes? Can you truly compare moral vs scientific arguments concerning stem cells, correction of genetic defects, medical manipulation of fertility (to achieve conception or prevent it), or maintenance of life by use of machines? Should you vote to protect wetlands, to prevent future floods, to maintain a fishing industry, or to allow resting places for migratory birds? Or are wetlands simply breeders for mosquitoes and places that could be profitably developed for housing or commercial purposes? Can you participate in a meaningful discussion of the dangers of nuclear reactors, or the merits or disadvantages of genetically engineered foods? On a more personal level, can you evaluate different potential diets, or interpret an advertisement for a medication? Can you read and understand the information inserts in medicine?

Ultimately, each of these discussions, and many more, depend on highly technical details that are not readily presented to the non-scientist. On the other hand, all scientists are expected to present their data in a manner that a layman can understand. Much scientific research is supported by your tax dollars through government-sponsored research programs. Each proposal for research is presented to a scientific board for evaluation, but the proposal typically also contains a summary that is expected to be meaningful to a congressman or congresswoman who will vote on the subsidy for the overall program, and meaningful to interested citizens who would like to know how their money is spent. That means you.

The goal of the scientist in this abstract is not to teach a lay audience the highly technical details of a complex proposal but to make the goals, limitations, and potential of the proposed research clear enough that you will understand the purpose and agree that it is a good idea and has the potential of producing knowledge of interest and value to you. Thus the first goal of this book and this course is to prepare you for this role as a citizen. What we hope to achieve is to give you a sense of how scientific data are collected and evaluated, so that you will be able to interpret the information inundating you. Thus throughout this book we will be emphasizing the scientific method.

EVOLUTION

We have chosen the approach of illustrating the scientific method through the study of evolution. We have chosen evolution for several reasons. First and foremost, evolution is the most important idea of the 19th Century and the most influential of the 20th Century. (Scientists almost never speak in absolutes, and almost inevitably qualify or restrict any statement that they make. I was therefore tempted to state, "evolution is arguably the most important idea…" but in this case there seems to be little reason to deny these claims.) Second, unlike, for instance, astrophysics or molecular biology, one needs relatively little technical background or familiarity with very abstruse and abstract topics to understand what is going on. For these reasons the topic seemed a logical choice.

SCIENCE IS AN ELF

Evolution, like astrophysics, lacks one essential of laboratory science, the ability to readily design and carry out experiments. It is possible to make predictions, which are in a sense thought experiments, and in some instances it is possible to design and conduct experiments, and we will address these issues as best we can. In all other senses, evolution is in every way a full science and illustrates the logic and construction of scientific thinking. That is, it depends fully on three elements that I define as an "ELF" principle: **E**vidence, **L**ogic, and **F**alsification. A scientific idea must be based on **evidence,** whether obtained by observation or experiment. The evidence suggests a link between two phenomena. A scientist will attempt to understand the link by establishing that one phenomenon causes another, or in other words he or she will form a hypothesis of cause and result. For instance, every year as spring approaches the sun gets higher in the sky and the days get longer. This is the **evidence**—both the length of the day and the mean temperature—that we can observe and measure. A reasonable hypothesis would be that the increased sunlight warmed the earth, rather than that the warming of the earth caused the days to get longer. This is the **logic** of the hypothesis, associating the heat that one feels in sunlight with the larger issue of gradually-increased warmth. Finally, the scientist will wish to test the hypothesis. The way that a hypothesis is tested is to try to disprove it: Can I create or envisage a situation in which the days will get longer but the earth will NOT get warmer? If so, does this disprove my hypothesis, or can I explain the seeming contradiction in a manner that still preserves the hypothesis? This is the **falsification** step (See Table 1.1). We will discuss these steps in considerable detail in the next chapter, and then use the principles throughout the book.

This means of analyzing information is not only not very difficult, it is something that humans do every day of their lives. Hunting-stage humans must have done it by observing, "if animal tracks from here go toward the setting sun (west), but when I am two days walk toward the setting sun, the animal tracks go toward the rising sun (east) then the animals must be heading towards a water hole between here and two days' walk west of here," (Fig. 1.1) or, "if that fat plant (cactus or succulent) contained water to drink, perhaps this fat plant also contains water" (Fig. 1.2). These are basically examples of classical syllogisms:

"If all antelope go to water in the evening
And if all antelopes here go west in the evening
Then there is water to the west."

Table 1.1. Evidence, Logic, Falsification

Evidence	Logic	Falsification
Weather gets warmer as days get longer	Sunlight warms the earth	Prevent all sunlight and warmed air from reaching an object
The lamp does not light when switched on	Perhaps it is unplugged	Verify that it is plugged in; plug it in. If it is plugged in, or plugging it in does not work, the hypothesis is falsified and we have to go to another hypothesis (bulb is burned out?)
Animals go west at twilight	Animals go to water	Follow animals, or determine when they return that they have drunk water
Cactus type A contains water; cacti type B and C have similar fat appearance	Fat plants contain water	Open cactus type B and C to see if they contain water
See bus leave stop; buses run every half hour	I walk 3 miles/hour and want to go 1 mile; walking is faster than waiting for next bus	Walk the distance; time yourself; observe if another bus passes

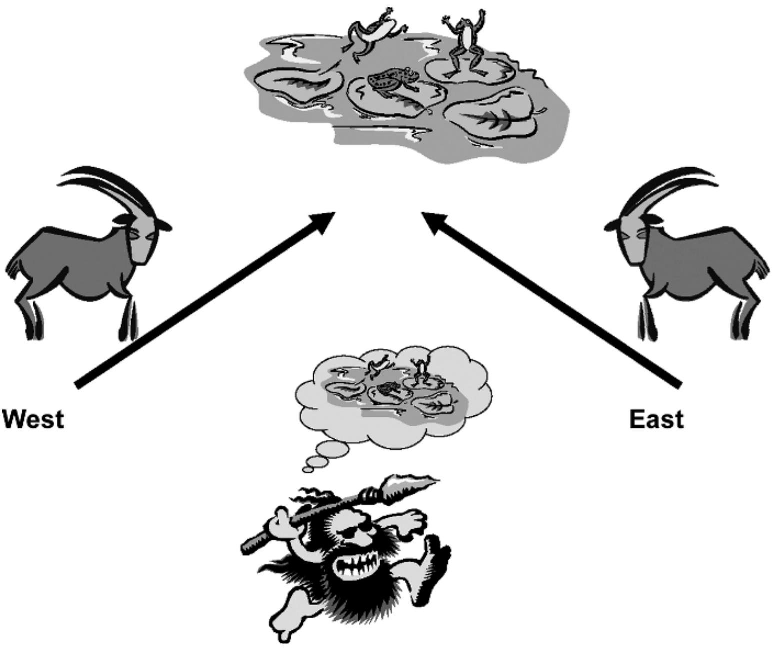

Figure 1.1. Inference and logic in a simple decision. The hunter-gatherer knows that antelopes seek water in the evening. When the antelope comes from the west, it heads toward the northeast. When antelopes come from a position several kilometers to the east, they head toward the northwest. Our hunter infers that water can be found somewhere at the intersection of these two tracks, or toward the north

When you buy a pen, and you say to yourself, "I really like that pen, but it costs five times more than this pen, and I usually lose pens in three days, so I had better buy the cheap one," you are using scientific logic, prediction, and evaluation; if you choose the more expensive pen, in spite of the evidence, you are conducting the experiment, "If my motivation—budgetary or desire—is strong enough, I will remember where I put the pen and gain the pleasure of owning it." Or again, suppose a candidate for mayor announces a platform of being "against crime in the streets". You are likely to say, "That's nice, what are you going to do?" If the candidate says, "I'll put all the criminals in jail," you are likely to say, "How are you going to do that?" If the candidate continues, "I'll arrest them all," you are likely very soon to wonder, "Is what the candidate suggests practical? Is he or she going to be threatening or harassing specific groups of innocent citizens? Can we afford the plan, whether it is better lighting, more police, more judges, more jails? Will the plan demand too much information about my life? If it includes restrictions on access to guns, knives, spray paint cans, box cutters, is this a good idea? How much will it restrict my life?" In other words, the candidate has hypothesized that a specific number of habitual criminals are the primary cause of crime (as opposed,

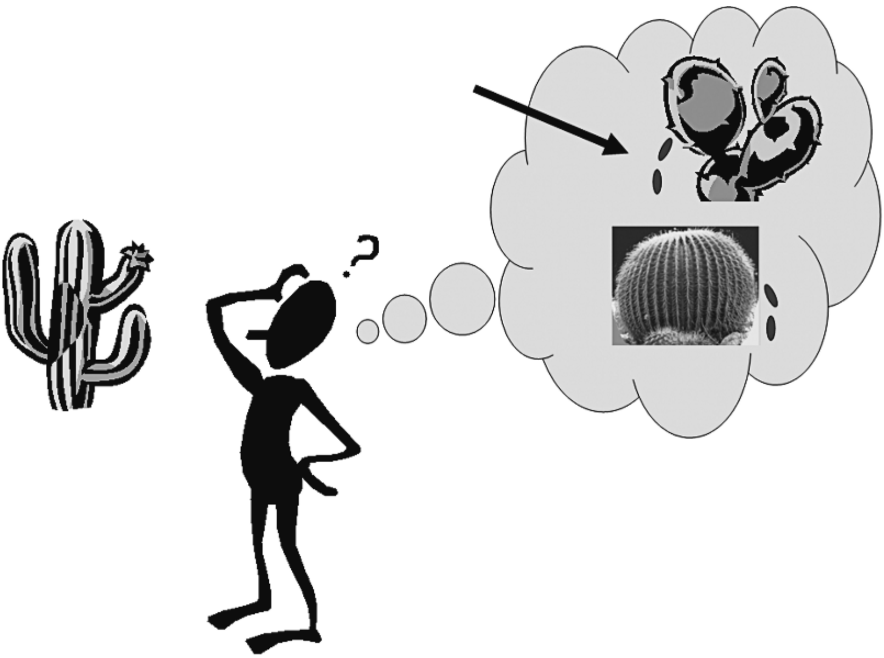

Figure 1.2. Generalization. Our hunter-gatherer is aware that, in dry lands, some plants with thick stems and leaves (which may be cacti, shown here, or succulents such as jade plants) store water in the stems and leaves. He is thirsty when he encounters a new type of plant, which has some resemblance to the cacti that he knows. He generalizes the first information to deduce that the new plant also stores water in its leaves, and thus finds something to drink

for instance, to poverty, lack of employment, insufficient care and protection of objects, lack of activities for teenagers and young adults, or other causes) and has proposed the experiment that isolating these individuals will eliminate the problem. You are asking for evidence that you will test against your own logic. You may well apply a form of falsification to the candidate's hypothesis: "Arrest rates differ from city to city and state to state. Do states with higher arrest rates, or more aggressive prosecution of criminals, have lower rates of crime? Do other factors, such as numbers of young men, play a role? How about the availability of employment, or of youth centers?" Collecting any or all of this information would in essence be an experiment in the same sense that a laboratory scientist designs an experiment. In other words,

IT AIN'T ROCKET SCIENCE (OR, IT IS UNDERSTANDABLE)

You apply the logic of science (hopefully) every day of your life. A local fast-food chain offers a huge ice-cream sundae that contains "only five calories"; you wonder if that's true (what the evidence is; how logically it can be sweet without sugar).

One mild day in winter, a friend remarks that the mildness is due to global warming; it crosses your mind that last week was a record low temperature. On television, an ad touts a "miracle brush" that can remove spilled dry paint with a single swipe; you are very skeptical and look very closely at the ad to judge if what is being shown actually happened. You notice, on another ad, for a weight-loss regime, that the actors in the "after" pictures are smiling, flexing their muscles, holding in their stomachs, and are turned so that their least flattering parts are hard to see, whereas in the "before pictures" they are not smiling and are making no efforts to hide their flab. Even a decision whether or not to walk to the next bus stop rather than wait, or to take a taxi rather than wait for the bus, is based on a hypothesis about the time on the route and your fatigue or energy.

This point cannot be made too strongly: The logic of science, and the structure of science, is simply human logic. It requires the same skills that we use on a daily basis, and is no more complex than that. There are only three things that seem to be difficult about science: its use of mathematics, its large and complex vocabulary, and the abstractness of many of its concepts. None of these presents an insuperable barrier to the student who wants to understand how science works.

MATHEMATICS AND TECHNICAL TERMS

Working scientists need to understand mathematics because quantification is a very important aspect of what we do. For obvious reasons, we need to know more than the fact that a volcano is a volcano. We need to know if it will erupt, which is a calculation based on the location of its magma (molten rock, lava), its past history and the history of similar volcanoes, what the earth is doing under the volcano, etc. If the volcano is not completely dead, we need to know when it is likely to erupt, and how severe the eruption is likely to be. All of these require extensive calculations, but even a non-mathematical person is likely to understand a scientist who says, "The molten rock moved this week from a half mile beneath the cone to within 600 feet of the cone, and the surface temperature at the cone rose 50° F. We consider the volcano dangerous."

Likewise, statistics is a large part of medical and sociological research. New medical treatments, and the licensing or banning of drugs, are based on comparisons of groups done by elaborate mathematical procedures. These procedures are based on analyses designed to eliminate inadvertent bias (smokers might also be heavy drinkers; a group of aspirin users might on average be considerably fatter than the non-aspirin users to whom they are compared; vegetarians may differ in lifestyle from non-vegetarians in more ways than in diet). The non-statistician needs to know how reliable others judge these statistics to be, and what the implications are, not the mathematics of how it is done.

Scientists use technical terms such as magma because they need other scientists to understand exactly what they mean. This is an important distinction from casual speech (though not from careful writing in any discipline). Listen to how many times "y'know" as in "It's like y'know, cool, man" translates to, "I haven't explained this coherently. I hope that you can fill in the gaps." This is not to say that common language is wrong or is not appropriate; it just does not have a place in scientific communication. One summer I worked in a factory, and a fellow worker liked to engage me in conversation. Unfortunately most of his conversation consisted of one obscenity, used as a noun, verb, and adjective: "That bleepin' son of a bleep of a bleepin' son of a bleep bleeped me!" My participation in the first part of most conversations usually consisted of non-committal responses as I trolled (in frustration) for the meaning of what he said. Was he talking about our boss? Politicians? His friends around home? His wife? Had someone insulted him? Short-changed him?

The vocabulary does not need to be daunting. Scientists use complex vocabulary partly because sometimes what the words describe have no counterparts in common language—no Biblical or other early writer truly imagined a molecule structured like DNA—but mostly because of a need for precision. Scientific language strives for a precision that assures that any worker throughout the world, on seeing a specific word, will have the same mental image. This is very different, and sometimes much drier, than common or poetic language. A poet may describe a lovely woman as having diaphanous skin and hair like gossamer, but the beauty of the poetry is that these phrases conjure an image rather than paint a picture; the language evokes an image unique to each reader, based on that reader's experiences and desires. Each reader will imagine a different woman and different circumstances, collecting impressions from his or her experience, and hopefully each reader will generate a different very personal but equally compelling and pleasurable image. Poetry frequently loses its value as it becomes more specific, as a film based on a very romantic novel may prove disappointing if the hero or heroine in the film is very different from the person one imagined. This is nothing like a police report, giving height, weight, hair shape, length, and color, age, skin color, shape of eyes, nose, lips, etc. … not very exciting, but everyone will have same image. Again: Which of the following passages better *evokes* autumn? Alternatively, if you had never heard of the word "autumn" (for instance, if you spoke Tibetan and were learning English) which would give you a better and more precise idea of the term?

"SEASON of mists and mellow fruitfulness!
Close bosom-friend of the maturing sun;
Conspiring with him how to load and bless
With fruit the vines that round the thatch-eaves run;
To bend with apples the moss'd cottage-trees,
And fill all fruit with ripeness to the core;
To swell the gourd, and plump the hazel shells
With a sweet kernel; to set budding more,
And still more, later flowers for the bees,
Until they think warm days will never cease,
For Summer has o'er-brimm'd their clammy cells.

Keats, Ode to Autumn

Compare Keats' poem to this description of autumn:

“The season starting at the fall equinox (normally September 21 in the Northern Hemisphere, March 21 in the Southern Hemisphere) and ending with the winter solstice (December 21 and June 21, respectively). In popular use, the dates are often constrained by holidays, as in the U.S., between Labor Day and either Halloween or Thanksgiving; or are defined by climate, as in northern North America many people consider that autumn ends with the first killing frost or the first snowfall.”

A scientific report is far more similar to a police report than to poetry—the goal is that everyone have as close to the same image as possible.

Common spoken English does not have this requirement. When an Englishman refers to a robin or to robin redbreast, he is describing a very different bird from the thrush that Americans call a robin (because the first English in the new world thought that the bird was the same). To prevent confusion, scientists would use a 300 year old tradition, from a time in which all educated persons spoke Latin, and would refer to the European bird by the Latin name of *Erithacus rubecula* and the American bird as *Turdus migratorius*. (The two-name system functions like the first or given name and last or family name system by which people in western societies are known. In the case of Latin names for animals, the capitalized first word is the equivalent of the family name. For the American bird, the name simply translates to “the thrush that migrates”. We will discuss the definition of a species and the terminology in Chapter 11, begining on page 157.) Likewise we know a turkey by the name of a country because of confusion with a large bird from that country. If one asks for “regular” coffee, in some parts of the United States one will get black coffee and in others coffee with milk. We also use several words to describe the same thing: a long sandwich with several types of meat, cheese, and lettuce may be called a submarine sandwich, a hero (sometimes even jiro), or a hoagie, depending on the region of the country.

As a more specific illustration of the point, let’s look at the word “significant,” which has several meanings. One, its original meaning, was “giving a sign,” as in “To the Greeks, it was significant that the general saw a meteorite the night before the big battle”. Another common meaning is “important,” “large,” or “considerable,” as “the loss was not significant”, and there are several variants of these, as in “significant other,” referring to a person with whom one is romantically involved. In biomedical sciences, the word has *only* a statistical sense: A difference between two groups that would occur so rarely by chance alone that the difference most likely supports the hypothesis of a relationship. For instance, if one measured lung cancers among 100 gum chewers and 100 non-chewers, and found 2 cancers in the first group and 3 in the second, the chances are that a repeat of the same assessment would the next time find 3 cancers in the first group and 2 in the second. There was no real difference, only a minor one dependent on chance. On the other hand, if one compared lung cancers among smokers, and found 10 cancers among the smokers and 1 among the non-smokers, the chances are that a repeat of the assessment would find a similar difference the next time, supporting the hypothesis that smoking can cause lung cancer. Statisticians can mathematically determine the probability that the results would be repeated, and biomedical scientists would call the difference between smokers and non-smokers significant. This is the only sense in which the word would be used by a scientist. In a scientific paper, "significant" NEVER means "important" or "meaningful". We will explore the precise meaning of the word "significant" in page 126.

SCIENTIFIC THEORIES AND HYPOTHESES

In common conversation, a theory is a guess as to how something works: "My theory is that the thermostat turns on the pump that circulates the water." To a scientist, a theory is not a guess but a hypothesis—that is, a logical inference as to how something works, or about the relationship of two phenomena—that has been tested many times, and each time supported by the test. When scientists review applications by other scientists for the support of their research, they often ask, "Is the work hypothesis-driven?" meaning, "Has this scientist created a model, based on preliminary evidence, as to how this works?" When many scientists have done this, and attempted many times to disprove their argument (falsification), and all the scientists come to the same conclusion, the hypothesis earns the title of theory. In general, calling something a theory means that it is logical, (logic); in many situations it is a plausible explanation of the relationship of two phenomena (evidence); and that many attempts to disprove it have failed (falsification). Thus other scientists can with some confidence consider the hypothesis sufficiently valid to base further, extrapolated, work on the assumption that the hypothesis is true. This is as close as we get to a higher level of certainty, a law. For a law, for instance, the law of gravity, we are sufficiently confident that all bodies produce and respond to gravity that we can base everything from planning the orbits of space ships to calculating tides to building very exotic medical and analytical machinery to aspects of atomic physics on the assumption that the "law" of gravity will apply, and we would be genuinely astonished if it did not. Although the terminology is a bit fuzzy at the borders, we do not have quite this level of confidence in a theory. We are only quite certain that a theory is true. A theory, and even a law, can potentially always be disproved, if an experiment or an observation can contradict it and no reasonable explanation can place the result into a category of interesting but comprehensible exceptions. The essence of science is testability, and thus everything is tentative pending the next experiment. It is quite humbling, and it is a source of considerable friction between scientists and public understanding. To a scientist, "the theory of evolution" means that the idea is well thought out, based on lots of evidence, and not disproved by any of myriad experiments—but there is always the outside chance that something that we have not imagined may someday disprove it, in the sense that we cannot predict that a lake will not suddenly appear in the middle of Arizona. To a scientist, the "theory of evolution" does NOT mean "a rather casual guess by a bunch of people who have not thought of other possibilities". And in any case, science addresses only the mechanics of how things work (which therefore can be tested) and never addresses the untestable.

ABSTRACT CONCEPTS

Finally, science demands abstractions, because in most instances the subject of the science is something that is not part of common experience. For instance, we cannot see a molecule. We can create an image of it, using specialized technology such as electron microscopy or atomic force microscopy, and we can view the image, or we can use various complex machines to detect the presence of molecules and determine their properties. What scientists do is to use their training about what these machines do so that they can construct mental images of the molecules as if they were 1,000,000 times bigger. In brief, the ability to think abstractly is the ability to make the abstract concrete. Throughout this book, we will attempt to help you, the reader, imagine some of these abstract and seemingly difficult concepts.

SCIENTIFIC PRESENTATION: FIGURES, GRAPHS, AND TABLES

There you have it! Science, its logic, and its findings can be understood by all students. One task that you should undertake, however, is something that is often neglected but is important, and which will considerably simplify your effort: look at the tables and figures that appear in the subsequent chapters. To working scientists, figures are not sidebars or attempts to render the text more fun. Well designed figures summarize important points, indicate relationships, and suggest further expansion of an idea. A figure such as that in Fig 1.3 can contain the ideas and relationships that would take pages to explain, and if one can grasp how it does so, one has saved oneself all of this memorization. Note how long it takes to explain in words what is shown in the graph, and how much clearer the graph is than the verbal explanation.

This figure illustrates the cost of printing magazines. One can read it as follows: Before a single magazine is printed, there is a cost of approximately $20,000 (point A). (This cost presumably includes the cost of the conception and design of the magazine, the collection of articles and pictures, the machines, and the building in which the press is housed, as well as salaries and incidentals. For someone trying to handle the budget, it would be important to know this initial cost.) For the first 20,000 magazines published, the real cost per magazine is approximately 2 dollars per magazine (calculated from the slope of the line between points A and B; the initial cost at 0 magazines is $20,000, and the cost at 20,000 magazines is $60,000. $60,000-$20,000 = $40,000, which is divided by the 20,000 magazines produced. The effective cost for the first 20,000 magazines, including the initial cost, is $60,000/20,000 or $3/magazine. After the first 20,000 magazines have been printed, presumably some basic costs have been met, and the cost per magazine falls to $5 per magazine. (Between 20,000 magazines and 40,000 magazines (point C), the cost has risen from $60,000 to $75,000, or $15,000 for 20,000 magazines.) The effective cost per magazine is $75,000/40,000 or $1.875/magazine. Beyond 40,000 magazines, presumably all background costs have been satisfied, and the

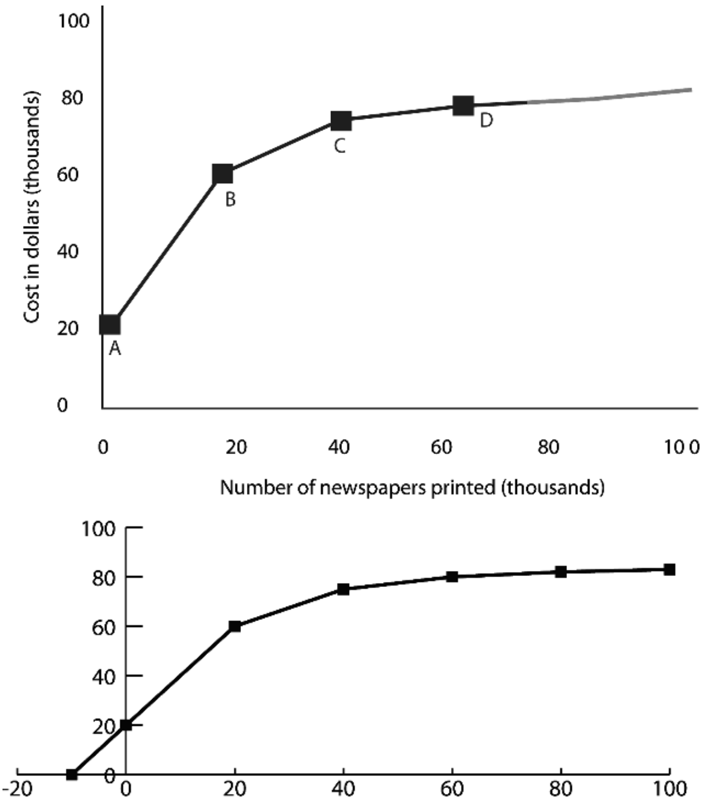

Figure 1.3. Graphical representation. As shown in the upper curve, before the first magazine is printed, $20,000 must be spent (point A: $20,000 for 0 magazines). This money represents paper stock, ink, staples, and costs for the building and personnel. If 20,000 copies are printed, the cost rises to $60,000 (point B), representing the baseline cost plus an incremental cost of $2.00/magazine ($60,000–$20,000 = $40,000/20,000 magazines). These costs presumably include the electricity, transport and delivery, and extra hours of labor. Between 20,000 and 40,000 copies (B to C), the incremental cost drops to $0.75/magazine ($15,000/20,000 copies), presumably because delivery costs do not increase much once the first shipment has been made. Between 40,000 and 60,000 magazines (C to D), the cost rises only $5,000, or $0.25 per magazine, for a total cost per magazine of $1.33/magazine ($80,000/60,000 magazines). Obviously there is higher profit in a larger production run if all the magazines can be sold. It is possible to extrapolate beyond point D (grey line) to see what higher numbers would per print run would cost, but extrapolating backwards to see what number of magazines would cost nothing, as shown in the lower curve (–10,000 copies), would be meaningless. Note how much simpler it is to read this information from the graph than to have to listen to an explanation

only remaining costs are supplies and salaries for the extra time, as the cost per magazine has fallen to approximately $0.25 per magazine between points C and D, for an effective cost of $80.000/60,000 or $1.33 per magazine at 60,000 magazines. One could even use the graph to predict the cost should the press decide to publish, for instance, 100,000 magazines.

CURIOSITY AND VALID SCIENTIFIC QUESTIONS

The last point to understand about how science works can be summarized in a single word: curiosity. All children are curious (just listen to conversations between 2- to 6-year old children and their parents) and some retain this curiosity throughout life, so that everything evokes a question: "How did this mountain get here? Why are male birds more brightly colored than female birds? How do insects survive freezing in the winter? Why do leaves turn color?" This curiosity can be summed up in an aphorism that is worth keeping in mind throughout this course: *"Phenomena are questions"*. In other words, there is a mechanism to explain how cells migrate to their proper places in an embryo, how the body fights an infection, how trees move water as high as 300 feet, how a bird or a whale finds its way half way around the world, or how the world is constituted such that flightless, ostrich-like birds are found in Australia, New Zealand, South America, and Africa, but not in Europe, Asia, or North America.

There are two related modifications to this last statement. The first is that science is about the mechanics of how things work. For this reason a question beginning "Why" is almost never a legitimate scientific question. Science is about the how, not the why, and a good question suggests a means of testing the how. It is rarely possible to test a "why". This is also why the scientific method presents far less confrontation with religion than many assume. A question beginning "Why", when it is not meaningless, is a religious question rather than a scientific one. For instance, "Why are rabbits brown?" may have a religious answer ("Because God made them brown so that they could hide"), but the scientific question could be any of several: "What is the selective advantage of brown color?" "What is the mechanism of inheritance of brown as opposed to other colors?" "What developmental mechanism arranges for pigment to appear on the back, but not the belly, of the rabbit?" "In what cells is the brown pigment?" (The cells are called melanocytes, or "black cells".) "How do the melanocytes carrying the brown pigment get into the skin?" "What is the biochemical pathway by which the pigment is synthesized?" "What is the biochemical structure of the pigment?" "How does a pigment molecule absorb light?" These questions can be carried deep into sub-atomic physics, and all are legitimate scientific questions, because, at least indirectly, they suggest possible mechanisms that can be tested. For this reason they differ from the non-scientific question "Why are rabbits brown?"

In summary, science is not an incomprehensible subject. The scientific method is an approach to understanding that is identical to the approach we use to understand any aspect of our lives. It differs only in that it has a series of specific codes and disciplines that allow a very structured means of asking questions, together with specific rules concerning what constitutes a meaningful answer. Understanding how these rules operate can demystify the world of science.

This book is primarily about the rules of science–how science works–as illustrated through examples of experiments, thought processes, and incidents in the lives of scientists, taking as a primary intellectual issue the development of a major theory. The subject of our inquiry and analysis will be evolution or, more properly, natural selection. The story of evolution encompasses three major steps that were accomplished in the mid 19th Century. The first was that thinkers had to conclude that the world was much older than the biblical approximation of 6000 years. Second, they had to accept the idea that species of plants and animals could evolve, or change with time (descent with modification). (This step also required a firm sense of what was meant by the term ‘species’, which itself depended considerably on new and confusing findings as Europeans explored the New World.) Finally, they then had to accept Darwin’s contention that this descent with modification was directed by the non-random survival of certain favored individuals in an intense competition for food, protection, nesting resources, and mates (natural selection). As we shall see, none of these ideas was particularly new or original in the mid 19th Century, but it was the connecting of all of these ideas that revolutionized the world. It was known, for instance, that farmers could improve crops by using only the seeds of plants displaying the desired characteristics. Breeders of dogs were aware that numerous variations of dogs were produced by selective mating. Thus species could vary considerably. Within a few hundred years, one could breed dogs to produce dachshunds, great danes, and bulldogs. What was not obvious, however, was how it would be possible to generate all the varieties of plants and animals in the world in 6000 years. Furthermore, the exploration of the new world had produced new conundrums or puzzles, based on the realization that different continents contained different animals and plants—a finding not readily obvious from the story of Noah’s Ark. We shall address each of these issues in turn. We will, however, branch into other, related subjects where appropriate. After all, all subjects are related in some sense: the exploration that led Europeans to reach the Americas would not have been possible without advances in astronomy and physics, and the history of 16th C Europe would have been very different without the struggles to acquire the riches of the Americas. Donne[1] would never have marveled at a woman, “Oh my America, my new found land!” It is sometimes very confusing, but ultimately exhilarating, to see these connections. Look for them. There are many rewards. First, you will be thinking like a scientist. Facts will become richer and more meaningful. Most of all, you will see that you will reduce the amount of tedious rote memorization you have to do because, once you see the connection, one fact necessarily leads to the next. For instance, Spain did not become a major power in Europe until it could draw on the resources of the New World. Once you know the date 1492, you can approximate the dates of the next events in Europe. No more getting the dates wrong by 200 years.

One last note: a well-developed, mature college-level vocabulary helps greatly to clarify issues. Therefore we will not attempt to “talk down” to you, the student, by using a less mature, less specific vocabulary. We will, however, in introducing a less common word attempt to explain it in passing. In doing so, we will use the trick of the King James Version of the Bible. The authors of that translation

[1] John Donne, To His Mistress Going to Bed

were faced with the problem that some of the English, mostly peasants, spoke Saxon, derived from the Germanic languages, while the upper class spoke French. They therefore repeated many terms, giving a Saxon and a French version of the same statement:

Gen.4
[**1**] And Adam knew **Eve** his wife; and she conceived (FRENCH), and bare (GERMANIC) Cain, and said, I have gotten a man from the LORD.
[**14**] Behold, thou hast driven me out this day from the face of the earth; and from thy face shall I be hid; and I shall be a fugitive (FRENCH) and a vagabond (GERMANIC, FROM LATIN) in the earth; and it shall come to pass, that

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STUDY QUESTIONS

1. Give an example from daily life and from a scientific/technical situation in which you can identify evidence, logic, and falsification. Clearly indicate which aspects are evidence, which logic, and which falsification.
2. From television or daily news, choose an example of a claim being made for a political or scientific issue and dissect the claim into evidence, logic, and falsification.
3. A medical report notes that there was a significant difference in survival between patients who walked at least one mile per day and patients who did not walk much. Explain what this statement means.
4. A weight-loss treatment is advertised using testimonials from satisfied customers. How would you evaluate the advertisement?
5. Why do we give Latin names to animals and plants?
6. Give examples of theories, laws, and hypotheses.
7. Choose a graph from a newspaper or news magazine and write a verbal description of the information found in the graph. Pay special attention to the

logical relationship between the data on the abscissa (horizontal or X axis) and the data on the ordinate (vertical or Y axis).

8. Describe three questions that you have asked at some point concerning how something works. What evidence would you need to answer your question?
9. What words did you not know when you read this chapter? What is the meaning of these words?