(excerpts from)
Lost in the Science Wilderness

An Essential Survival Resource for the Scientifically Perplexed

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Part I. Orientation

1. Introduction

I am a scientist, a born scientist. That is, I grew up asking why, how and what, persistently and early. I drove my parents, particularly my father who was a meteorologist, nuts with my incessant questioning. (Mom deferred some of my questions to him so he bore the brunt of it.) I had to understand how everything worked. I had to know the cause-and-effect sequences behind bulldozers, telephones, lava, starry nights, wriggling fish, cat’s tongues, dog’s noses, space travel, snow, Jell-O and goosebumps; in short, everything. The answers that satisfied me came from science. I had to become a scientist as I grew up. I had no choice. Science never had to be justified to me.

This book is not for me.

This book is by me, for you.

You are a non-scientist. Well, maybe you’re not\(^1\), but that is my intended audience, judging by the book’s sub-title. By a non-scientist, I mean someone who never pursued the study of science, not because he or she never had the opportunity, but someone who had the opportunity and passed it by in favor of some other course of study or vocation. You became or are becoming a lawyer, a salesperson, an art teacher, a welder, a novelist, a stay-at-home parent or, instead of anything productive, a politician. \(\smile\) Some non-scientists are science buffs. They enjoy reading about discoveries and mysteries and watch science and nature documentaries often. If you are one of those, you understand the basic instinct of a scientist; an almost insatiable curiosity about the natural world. Other non-scientists are different. They may respect science and appreciate its usefulness demonstrated through all the gadgets and medical breakthroughs, but not “get it.” Why on Earth would anyone \textit{want} to have an explanation for how a sapphire gets its deep blue color, an accurate mental picture of where the Earth is in the Milky Way galaxy, or an understanding of nearsightedness? No matter what type of non-scientist you are, I hope that this book will give you some more insight into science and scientists.

For the title of this book and the concept, I have chosen the analogy of you being lost in a partially tamed wilderness, with no sense of direction or essential survival skills, and myself as an intrepid and trustworthy guide to lead you around, teach you to survive and ultimately lead you out. Once out, though, I hope that you’ll have appreciated the beauty and wonder of the place so much that you’ll want to return. You will respect but not fear the caves, rivers, weather and animals. You may even bring someone along to show them this wilderness; a friend, a coworker, a spouse or, especially, a child.

In this book, I will attempt to do three things for you. The simplest thing will be to give you a brief tour of where we are in our current understanding of the natural world. This part, \(\text{II}\),

\(^{1}\) If you are a scientist, or a naturally scientifically curious person, then I am preaching to the choir. But, in the words of Pedro Cortez, “A little choir practice is good now and then.” (King’s College commencement address, May 18, 2008)
will therefore be similar to most of your standard science education in that it will tell you what things are, where they are, and how they are related to one another. (The hip bone’s connected to the thigh bone…) If it’s been a while since you had high school science or if the high school science education you had was of very poor quality or even if the fault is yours for not having paid enough attention to science in high school, this part of the book will help you remember (or learn) the basics that you’ll need to understand science in our modern world. This part of the book is similar to a road map with a big red arrow saying “You are here.” Different chapters and sections will be different maps, but all will let you know where you are, figuratively speaking. Since you’ve probably had a bit of this already in high school biology, chemistry and physical science, I’ll be brief in the details.

But, I’ll spend a considerable amount of time explaining why scientists think that things are the way I describe them. For example, scientists think, they do not believe, but think, humans evolved from ape-like ancestors not because Darwin said so, but because the overwhelming evidence indicates that humans did do just that. Part I will introduce you to the philosophy and methods of science. This is not so simple as part II, because you will not be learning about facts and theories in science but rather learning and thinking about science itself. This is all about the criteria for evidence and for valid scientific theories. We’ll see that not all possible explanations are valid scientific explanations. But what are the rules scientists use to decide what evidence is or is not acceptable or what explanations are scientifically useful? Who decided that these rules and not others would be used? Part I will answer these questions. In doing so, it will go beyond your familiar high school science and talk about philosophy, something most high schools are afraid to mention. Because philosophy is not a standard part of a public education, most people have difficulty following scientific issues, especially in cases where science suggests or demands that we rethink or change some of our most familiar ideas or practices.

You may have had several bad experiences in science courses. From conversations with non-scientists, I think many of these bad experiences involved memorization; Kingdom, phylum, order; Adenine-thymine and cytosine-guanine, Mercury-Venus-Earth-Mars…, the Krebs cycle, etc. Of course some memorization is necessary when learning anything; gas pedal on the right, brake on the left; pillage then burn, etc. But if memorization is all you remember (!?!?) from science, then you have a very inaccurate idea of what science is all about; understanding. When done right and given enough time to develop, scientific theory-making leads to a set of interconnected cause-and-effect relationships that make sense. It all hangs together and fits. So, learning science properly becomes a matter of memorizing and understanding a few basic principles and logically applying those principles to new situations. A good analogy is arithmetic. A young student learns that $2 \times 4 = 8$, $7 \times 3 = 21$, $7 + 6 = 13$ and so on. That student does not memorize that $23 \times 47 = 1081$ but rather uses the basic building blocks of arithmetic to logically figure out more complex problems. This saves considerable time, because there are an infinite number of more complex problems! One of the things I’ll try to do in this book is to give you the basic building blocks. Most of you will already know many of these building blocks, but I’ll emphasize that they are basic and important. Several examples throughout the book will show you how these basic building blocks can help you easily understand more complex issues like energy supply issues, global warming and evolution.

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2 If none of these seem familiar to you, don’t freak out. Keep reading. My point is that learning science is about understanding, not memorizing. I don’t remember the Krebs cycle, either.
For example, the laws of Chemistry support Biology, letting biologists infer all sorts of details about the innards of organisms based simply upon what they eat and excrete. Biologists expect that Chemistry is valid and useful to them, as are the laws of Physics.

The reverse is also true. Nothing ever found in biological research has gone contrary to the laws of Physics. If it did, biologists would be very upset, well, and maybe a little proud that they caught their physics colleagues by surprise! Physicists would freak out. They would all, biologists and physicists, work together, argue, fight and accuse one another of all sorts of incompetence UNTIL it would all get settled. It can get settled in only one of two ways: 1. An error is found in interpreting the research and it turns out that the laws of physics were never violated in the first place. 2. The laws of physics are either incorrect or at least inaccurate and must be modified. In almost all cases, #1 is what happens. Somebody does a calculation based upon some approximate data and some simplifying assumptions and concludes that an observation they have made violates the known laws of science.

A good example is the “urban myth” about scientists supposedly proving that bumblebees can’t fly. Popular especially in the 1980s and 90s, this myth relates a story about an unnamed scientist applying the laws of aerodynamics to “prove” that bumblebees can’t fly. The tale is usually told as a caution for the listener to not believe everything that science tells them. As I understand the history of this myth, it stems from someone trying to understand bumblebee flight by applying some known aerodynamic laws in a very simple way, the result being that the laws did not support the idea that bumblebees can fly. It turns out that if you work harder, much harder, at really accurately describing how the bee’s wings move, and spend some quality time watching the bees carefully, you find that their flight is possible within the laws of physics.

So, understanding how science works and how the sciences work together will help you remember and understand all those seemingly random facts you may have learned (or relearned). It will also help you recognize when science is being done poorly or described poorly (as in the bumblebee episode). Understanding beats memorization any day. It’s the attention to understanding which is lacking in so much of our schooling in science. But, there is a worse sin. Perhaps the most difficult task I will undertake here is to place science, its methods and its findings, in the context of the human societies we live in. This task comprises part III and attempts to do the job that I think most science instruction fails at, miserably. But, in order to think about how science changes our perspective on the world, we must first understand what science is (Part I) and what we know from it (Parts II-V). Therefore, I save the topic of societies’ interactions with science for last. If you’re the impatient type, you may want to skip ahead to those parts. Go ahead, I won’t mind. (Nor will I know!) I hope that if you do you’ll start paging back to the other sections for the background you might need. These latter parts will also motivate some readers that the previous parts of the book are indeed worth reading.

Covering all of natural science is a big task for a small book. Much larger books than this have tried this with some success. So, what am I leaving out? First of all, the math! In a few places I’ll show you an equation or a calculation, but mostly I’ll stay away from the mathematics and stick to other ways of describing a theory or law. Secondly, I’m focusing on not all of science but what I consider to be natural science’s greatest hits. By natural science, I mean those parts of science that do not directly study human activity. The social sciences, psychology, sociology, political science and economics, etc. handle subjects that are “man made” in a sense. Natural science would be that part of science that even an extraterrestrial would recognize and understand. And I will only focus on the big ideas that are central to understanding the big picture. Third and last, I shortened the book by trying to stick to the science and not write about
the scientists. Most popular science writing tends to dwell on personalities and histories, in part, I think, to make science more accessible to non-scientists. I think the opposite is true. If I constantly distract you with details of the lives of scientists, your focus will be taken away from the concepts that these scientists developed. It’s the concepts, not the scientists, that are ultimately important. Coming back to our hypothetical extraterrestrial scientist, I’m sure he (she, it?) would know all about the law of gravity, but he would have his own Newton and Einstein to thank for his understanding of it.

The Power of Scientific Thinking
Throughout the book, it might seem to you at times that I am tooting my own horn. “I am a really smart guy, like all scientists, and you should be really impressed by me.” That is not my intention and I certainly hope you don’t take any parts of the book this way. My messages to you are, ultimately, look at what a wonderful tool science is and look what you can do with this tool.

Like a marvelous invention, say the telescope, science lets you learn new things and see old things in a new way. You don’t have to have invented the telescope, or even be able to make one yourself, in order to understand its use, appreciate its power and rely upon it. In this analogy, think of the great scientists as the inventors of amazing tools. The tools they invented are theories that bring together facts in a logical and understandable way. The average, everyday scientists (like me) that use these theories can be thought of as technicians that build telescopes and improve on the original invention. We also point the telescope (apply the theory) to all sorts of things the inventors never got around to. You, the non-scientist, may think that none of this has anything to do with you. Nonsense; you can look through the telescope and see your world as you have never seen it before. It will still be the same world as before, but your perception of it will change dramatically.³

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**Quote**

The progress of human knowledge is measured by the increased habit of looking at facts from new points of view, as much as by the accumulation of facts. The mental capacity of one age does not seem to differ from that of other ages; but it is the imagination of new points of view that gives a wider scope to that capacity. And this is cumulative, and therefore progressive.

George Forbes, *The History of Astronomy*, p. 2

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**References/further reading:**

Bumblebees and flight
http://en.wikipedia.org/wiki/Bumblebee contains a quick summary of the origins of the “urban legend” about bumblebee flight impossibility. The punch line, showing that science does, in fact, agree that bumblebees can fly, comes from an aerodynamicist at Cornell University.
http://www.news.cornell.edu/releases/March00/APS_Wang.hrs.html

³ For me, the internal gears and workings of photocopiers are mysterious and magical. I bow to the high priests of Xerography that they can create such machines; likewise the lower clerics who service these temples of office magic. I can but use and appreciate these machines and what they can do for me. I still put the paper in wrong about 12% of the time. If I learned how all its parts were put together, I’d have a deeper appreciation and would probably only screw up the paper once in a while.
History and personalities in science
Bill Bryson’s book, *A Short History of Nearly Everything* (Broadway books, 2004), is loaded with anecdotes and detailed personalities of the prominent and not so prominent in the history of science. It is a very interesting read, but if you’re looking for insight into a particular scientist, a more focused and comprehensive source is *A Dictionary of Scientists*, edited by John Daintith and Derek Gjertsen (Oxford University Press, 1999)
2. Rules of the Road

To begin our exploration of the Science Wilderness, we have to establish some rules by which we will do our traveling, such as; drive on the right side of the road (when there is one), put out our fires when we leave a campsite, always wear bug repellent and sunscreen, don’t eat the yellow snow, etc. The rules for science are fairly straightforward and easy to learn. The trouble is, they are just as easily forgotten or set aside because, although straightforward, they demand a great deal of dedication and care to follow. You probably began learning them in elementary school.

I have the pleasure of regularly serving as a judge at science fairs. For those of you unfamiliar with this American educational tradition, it involves elementary or middle school children, usually about ages 8-13, who devise and carry out some sort of scientific experiment. It usually goes something like this:

Suzie wants to answer the question Does Miracle-Gro fertilizer really make plants grow faster? To answer this burning question, she will plant 20 identical seeds (let’s assume they are peas…they usually are) in 20 identical little pots. These plants are all then set in the same environment, the same light, same temperature, etc. Everything is identical except that half the plants receive just water and the other half receive water fortified with the appropriate amount of Miracle-Gro. She proudly beams to me about how this experiment proves that Miracle-Gro really works.

I have been through this more times than I can recall. It is so predictable, so staged, so trite and so beautiful. It’s beautiful because it’s not about Miracle-Gro at all (or about battery life, or how many unpopped kernels of corn are left behind by various brands of microwave popcorn). It’s about a method for getting at the truth, for being sure that your answer is the correct one, and being able to prove to others that you have the correct answer.

Pause for a moment and think of why Suzie’s experiment shows that Miracle-Gro is effective.

No, I really mean it. Stop reading, pause and think.

My first question to the hundreds of Suzies I’ve encountered usually goes something like, “Why not give them all Miracle-Gro? Why do you have to give just water to the others?” If Suzie is really getting the big picture, and she usually is, I get a quizzical look and an uncomfortable pause while she tries to think of a way to politely say to a grown-up, “Because, you big idiot, if I didn’t give just water to the other plants I’d have nothing to compare the Miracle-Gro plants to.” “Of course,” say I, “that is exactly why the other plants are there.” I then apologize for acting like a teacher and testing her like that. But I keep on pressing to find out why she did the other things that she did. It’s very important that other than the Miracle-Gro, everything else about the plants is as identical as she could manage. Why? Suzie and her classmates have a little more difficulty with this one, but I hope you see the answer. If all other conditions in the environments of the plants are not kept the same, you can’t be sure it was the Miracle-Gro and not some other factor that caused a difference in plant growth.

Below, we’ll develop much more sophisticated language to describe Suzie’s experiment and more complex experiments. But, the essential understanding of why her experiment works is what understanding science is all about. It is so easy to understand but very easy to forget when money, time, beliefs, social and political forces sway us away from the answers science is giving us.
Epistemology

Ouch! There’s nothing like starting off with a nineteen-dollar word. Epistemology is not a scientific term but a word from philosophy. Epistemology is the investigation into the foundations and nature of knowledge itself. How do we know what we know, or at least think we know? The study of epistemology focuses on the way we acquire knowledge and how we can distinguish between what is true and what is false. The various answers that have been offered for this question are too numerous and subtle to go into here, so I’ll just summarize the basics.

For our purposes here, let’s divide the answers about how we know into three fundamentally different categories. First, some think that we “know” something when we look inside ourselves and think rationally. In doing so, we find that we are sure of some things and not so sure of others. Those we are sure of through pure reason we know. This idea, which we’ll label rationalism, places the source of knowledge within us (called a priori knowledge which means, in Latin, “before”). If this person wants to know “the Truth” he need look no further than his own mind to form a rational, consistent collection of facts. The outside world is largely irrelevant, and may not even really exist.

In a second perspective, others contend that we must connect with some realm of ultimate knowledge and meaning. This realm is necessarily supernatural in the crudest sense, that is to say, above nature. It may be spiritual but it need not be. In this point of view, our physical reality is usually regarded as a pale copy or distant cousin of the realm where truths reside. For Plato, this realm was one of pure truth and the ultimate good in ethics. For religious thinkers, this is the realm of the gods. Knowledge from this realm may be glimpsed through contemplation or meditation or it may be revealed by seers or prophets. Let’s call this point of view mysticism.

The third major category is the one that insists that to learn anything we can only look to the outside world through our sensory experiences. Truth is ultimately grounded in what we can see, hear, feel, taste or smell. This is called empiricism. This is the position that science takes, at least as a working principle.

Which if any of these is correct? This question is one of those “ultimate” questions about the nature of reality. Philosophy deals with questions like this. Trouble is, most of these questions go unanswered, or at least have so far gone unanswered for about 3000 years of modern human civilization. There are lots of arguments for and against the various answers, but no definitive way to say A and C are false and B must be correct, or vice-versa or versa-vice. As you may learn if you take a philosophy course or read about philosophy, it’s more about questions and less about answers.4

Empiricism forms the basis of the philosophy of science. Science assumes that you must gather objective evidence from the outside world. You cannot form scientific conclusions unless your reasoning is firmly grounded in physical evidence. You must understand that empiricism is assumed to be valid by scientists when doing science; defending its use is not part of science but rather part of the philosophy of science. I’ll use the label “philosophy of science” whenever I discuss not science itself but how science fits within the larger context of human knowledge.

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4 Which is not to say philosophy is worthless. It has ruled out some very harebrained ideas. Studying philosophy provides opportunities for us to question many of our long-held assumptions about our world, societies, governments, art, morals, etc. It requires us to search our hearts, minds and consciences and be accountable for our ideas. It can be said that maybe you can’t do anything with philosophy but philosophy does something to you.
So, if philosophers can’t decide about how we obtain our knowledge, why are scientists so confident in choosing empiricism? The answer is very simple:

**EMPIRICISM WORKS**

Empiricism works when you are investigating the physical universe. It works like nothing else, as the world soon discovered when Galileo started insisting that we always use it when we ask questions about Mother Nature. Humanity spent several thousand years making very little progress toward understanding the workings of the physical universe. Once we started allowing only the use of physical (that is, sensory) evidence our knowledge and understanding of the physical world took off and advanced so rapidly that we can rightly call the period following Galileo (1600-1800) the Scientific Revolution.

It’s important that I add the following caution. Empiricism works when applied in the process of doing science, that is, when designing and carrying out experiments and when creating or evaluating theories. Science is not saying that the physical world is all there is. All it is saying is that when doing its business science will act as though there is only the physical universe. We’ll revisit this when we get to the dangerous swamps in the Wilderness where science and religion mingle in mire and muck.

**Science: Terms and method**

I’ll discuss the history of science in greater detail in the next chapter, so let’s get back to the business of getting to know about the world in a scientific way. Science proceeds by gathering facts and developing theories. These terms are perhaps the most confused when discussing science so let’s begin with some definitions of these words as they are used in science.

**Fact- An objective observation or measurement of something physical that all qualified individuals agree upon**

This is my definition for our discussion, so I’ll elaborate. An observation is anything gathered directly or indirectly through the five senses: seeing, hearing, smelling, tasting and touching. Objective is important so that what is observed won’t be a matter of opinion; that’s subjective. “Qualified” is a loaded word, but it’s important to establish that the person making an observation or measurement is qualified to do so.

For a good example, consider a group of people together in the same room. Assuming there are no drafty areas in the room, the temperature is the same throughout. Will everyone agree as to whether the room is cold, cool, warm or hot? If the room is near a “normal” room temperature it’s likely that there will some disagreement. The sense of touch surely qualifies as a means of physical observation. The problem is, whether they feel cold or hot or comfortable is very subjective and depends upon a bunch of things including clothing style, body metabolism and personal preference. So, whether the room is cold or warm cannot be established in an objective way just by asking the room’s inhabitants. Can we figure out a way to objectively determine how hot or cold the room is? How about using a thermometer?
Who’s qualified to read a thermometer? If you can, you might think that anyone can, but remember that there was a time when you couldn’t. Thermometer reading is a skill that must be learned. You must become qualified to read one. Following a severe injury, one of the questions on everyone’s mind is, “Are any bones broken?” Reading an X-ray image is something that requires a qualified person. So does “observing” words written in French and translating them into English. I can do neither, so I am not very useful for reading X-rays (I’m the wrong kind of doctor) or translating French (“Boucher” is about all the French I understand). Being a physicist, I am qualified to read many types of thermometers, though. Sometimes I must defer to qualified people and sometimes I’m the qualified person, so there’s a substantial amount of trust needed here.

What if all the “experts” are wrong? That’s possible and will eventually be discovered if we keep asking questions and doing experiments (the rest of this chapter). What if all the “experts” are lying to us? Ahhh…a conspiracy! That is also always a possibility, but let’s not assume that for now. We’ll deal with that in a later chapter when we discuss pseudoscience.

Although scientific facts are ultimately rooted in sensory experience, it does not follow that personal experiences are necessarily facts. For example, I might tell you I like cheese. If you trust me you may consider that to be a fact, but be very careful here. (I don’t mean be careful about trusting me. Of course you can trust me!) All you really know is that I said I like cheese. That’s a scientific fact because other observers can agree with your observation by overhearing me or seeing a video of me saying it. Whether I like cheese or not is still up for debate, and may never be known.  

This reliance on objective, verifiable observation is essential to the definition of a fact in science. It’s one of a few good reasons why science needs to communicate within its community and with the public in order to work.

Quote
Science is facts; just as houses are made of stone, so is science made of facts; but a pile of stones is not a house, and a collection of facts is not necessarily science.

To continue on, let’s just assume that we have a way of getting some facts. Now what do we do to transform a pile of facts into science? I now give a definition of the word theory that will take a few pages to fully explain.

Theory- A theory is an idea, an organizing principle, about physical causes and effects that explains why certain facts are the way they are. A theory not only explains what is known but can also predict the outcomes of future experiments or facts not yet discovered. These predictions can be tested by comparison to new and existing facts, which is crucial to the success of science.

Facts are discovered. Theories are invented. A theory is an invention of the mind as surely as a song or a sculpture. A fact may be, for example, that the glaciers in Finland are receding. A theory would be an explanation as to what is causing them to recede. Theories link causes and effects. Theories say, “This is how it works.” For one set of facts we can have many

5 Or maybe it will. My liking cheese is, so far, a subjective statement by me. Can it ever be scientifically verified as fact? Maybe. Neuroscience is beginning to map brain function and can tell, in a typical or normal brain, if someone is being truthful or not, if they are shocked, aroused, etc. Keep your eye on this field of science in the next couple decades for some truly remarkable and unsettling discoveries!
competing theories. Einstein and Infeld described the process of science as the “attempt of the human mind to find a connection between the world of ideas and the world of phenomena.” There are an unlimited number of ideas but the challenge is to find ones that agree with what the universe actually does.

If a theory is in a very early stage of development where it may have not yet been tested or tested only in a very limited way, scientists will refer to the organizing principle as a hypothesis rather than a theory. In general scientific use, the word theory refers to a hypothesis that is pretty strong because it already has passed some tests. It’s tricky, though, because there is no magical moment when a hypothesis becomes a theory. So, my advice is to not worry about a fine distinction between the two. Just keep reading and a feeling for how the words are used will become stronger.

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Quote

A fact is a simple statement that everyone believes. It is innocent, unless found guilty. A hypothesis is a novel suggestion that no one wants to believe. It is guilty, until found effective.


Note that Teller claims that a hypothesis is of a suspect nature until proven somehow. In everyday conversation, most people use the word theory like a scientist would use the word hypothesis. Someone may drone on at a local bar about a “theory” as to why the Chicago Cubs have not won a World Series since 1908. In that context, a “theory” is a wild idea, just a speculation. On the other hand, if an idea has a lot of evidence behind it, then it is commonly referred to as a “fact” or “true.” This is very different from the way science uses these terms and it can be confusing. I’m sorry about that, but it’s not my fault! Just be careful in your own thoughts and conversations when inside and outside of a scientific context. Outside a scientific context, the word “theory” is attached to a half-baked and doubtful explanation. In science, a “theory” is a very successful and powerful idea.

Let’s keep going deeper into my above definition of a theory. In science, it is assumed that physical causes lead to physical effects. Why? Because in order to test a theory, we have to be able to know whether a proposed cause is (or is not) present and leads (or does not lead) to a certain effect. To say with certainty that a cause is or is not present, we have to be able to observe it objectively. It is the same with the effects, the observations in experiments.

A chemistry professor I know summed this up by saying to his students, “Evil spirits are not to be mentioned in your lab reports.” If the results of the experiment were not as they should have been, the chemistry student must strive to find a physical reason why; was an amount measured incorrectly, was the temperature right, etc. To blame some malevolent spirit or vengeful god of chemistry is to stop doing science and begin practicing superstition (and fail the lab report). Many ancient and primitive religions relate to the natural world by invoking spirits and gods to explain the existence of physical events, such as floods or diseases. These types of explanations satisfy one’s natural curiosity, at least a little bit. They do tell you why, but then leave you with a nagging follow-up question. If an evil spirit caused the cattle to die, why did the spirit do this? Unless you can get inside the head of this evil spirit and know its thoughts and motivations, the explanation is incomplete (and does the spirit have a head in the first place?). How could you predict when the cattle may be subjected to this again? You can’t. If the cattle

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6 To avoid cultural bias, I could write: Some bloke at the local pub might rabbit about why the Netherlands has never won a World Cup. Same idea but the beer is probably better at the pub.
are sick another time is the evil spirit the cause again? You can’t know. It’s an explanation that
gives you nothing except other questions about a spirit that may or may not actually exist.

Quote
“If it might be wrong, it’s science.”
Moti Ben-Ari

Continuing on with my definition, I say that a scientific theory has to be testable. It has to
make predictions that may or may not turn out to be true. A simple example would be a theory to
explain why the cocktail called a screwdriver makes people intoxicated.\(^7\) A screwdriver is a
mixture of orange juice and vodka and vodka is itself a roughly half-and-half mixture of alcohol
and water. Let’s assume that we’re confident that the active ingredient is not the water in the
vodka and focus on just the alcohol. Pretend for a bit that we know nothing about orange juice,
alcohol or intoxication. We make a few observations of screwdriver-drinking people dancing
with lampshades on their heads and making 3 a.m. phone calls to ex-girlfriends and yearn for an
explanation. Let’s say two theories are proposed. One theory states, “orange juice causes
intoxication” whereas another states “alcohol causes intoxication.” Each theory explains equally
well the data\(^8\) that screwdrivers cause intoxication, but each make different predictions for a
situation where only orange juice is consumed. The “orange juice” theory would predict that
intoxication would occur. The alcohol theory would predict that intoxication would not occur.
Each theory is a valid scientific theory in that it puts forth a physical cause for intoxication and
that cause is testable in the right experimental setting. In this case, one theory is supported or
confirmed (alcohol theory) and one is not supported (orange juice theory). We’ll come back to
this experiment later in the chapter and embellish it with some technical terms, but the essentials
can be understood without all the jargon.

It is very important to pause here and think about what this means for the alcohol theory.
Is it “true?” If by true we mean absolutely certain, then, no, it is not “true.” Maybe the ice cubes
caus ed the intoxication or maybe it was some contaminant on the glasses used in the experiment.
Maybe the people involved the experiment were not typical people and the results can’t be relied
upon. Maybe the phase of the moon or the current Federal Reserve short-term interest rate have
something to do with it. How many experiments (repeats of the same experiments and other
experiments; different glasses, different moon phase, etc.) would we have to do to be 100% sure
the alcohol theory is true? Obviously we never can be 100% sure. REMEMBER THIS:
Scientific theories are never completely certain. There is always the possibility that tomorrow a
new experiment or some new data will make us form a new theory or modify an old one. That
makes science adaptable and self-improving. Like the quote above says, the greatest thing about
science is that it can be wrong.

Quote:
“How can one be certain, in any particular case, that one has selected the correct cause of an
event out of the huge, indeed infinite, number of possible causes?”
Colin Howson and Peter Urbach

The essential problem of certainty, or lack thereof, in science comes automatically with
inductive reasoning. In inductive reasoning, one tries to create a general truth from many

\(^7\) “Drunk” doesn’t sound very scientific does it? Let’s go with “intoxicated” so we can have fun putting on airs.

\(^8\) Woohoo! More fun putting on airs! “Data” comes from Latin and in science refers to the body of facts we are
trying to explain. It’s far fancier to use than “the facts.” Datum is singular and data is plural. Impress your friends
and intimidate your enemies!
specific facts. That general truth is more reliable when one has more facts, but it can never be certain. To answer their question, Howson and Urbach conclude that we have degrees of confidence, and never certainty. All we can hope for is the increasing probability that our theories accurately describe nature.

**Deductive reasoning** is pretty much the opposite of inductive reasoning. Deduction takes the thinker from a general principle, applicable to a wide variety of situations or objects, to a specific situation or object.

To understand both types of reasoning, consider familiar experiences with hot cups of coffee or tea. Many a time you’ve set down your fresh, hot beverage and have been interrupted or distracted by something else. When you return to the cup, it has become cold. Inductive reasoning leads to the general principle that hot objects left alone will eventually cool down. Armed with that principle, you deduce (use deductive reasoning) that when you pour yourself a replacement cup, you will not let yourself get interrupted again for fear that this cup will also cool down. Induction allows us to form theories and deduction allows us to test them. Deduction gives us predictions of what might happen in a given situation based upon a theory. Theories must be testable or they are not scientific.

An example of an untestable theory comes from the field called parapsychology. Parapsychology deals with alleged powers of the human mind that go beyond the normal abilities. These superpowers include reading others’ minds, remote sensing and foretelling the future. So far, all attempts to measure mind reading and such in a laboratory under controlled conditions have been unsuccessful or inconclusive. A simple conclusion would be that the human mind is incapable of such feats. Some researchers for whom this conclusion is unpalatable have a more clever explanation. Such superpowers cannot operate properly in the presence of the “negative energy” given off by skeptical minds nearby. So, if a researcher who believes that mind reading works conducts an experiment and he does observe mind reading, then under this theory we should accept his results. If, on the other hand, a researcher who doubts the existence of mind reading conducts her own experiment and does not observe it, then it’s not because mind reading doesn’t work but because she is skeptical. Can you see that there is no possible way to disprove this theory?

So, to reiterate, if a theory can’t be disproved under any conceivable experiment, then a theory is unscientific. Does that mean it’s wrong? No. In a scientific sense it’s not even worthy of being wrong. It is nonsense and a waste of time. A theory is only a valid scientific theory if you can think of a possible experiment that might disagree with a prediction of the theory. By valid, I mean that it is allowed in the arena of scientific competition. This arena can be thought of as a gladiator game where two theories fight it out to the death. The dead theory, the one disproved by experiment, is dragged off the field and is replaced by a new one, if there is a new one available. (It is possible that there are no gladiators in the arena.) If the new theory survives all experiments and the old theory doesn’t, then the new replaces the old. If both have survived all experiments done so far, they both stay in the arena. This game has no time limits and no limit to the number of gladiators that can be present at once. At times, it can be a big challenge to keep track of what’s going on!

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9 Thomas Bayes was a British mathematician in the 1700s who first expressed this idea of probability as a degree of belief. The concept is very important in the philosophy of science and is referred to as Bayes’ Theorem or Bayesian probability.

10 See [http://skepdic.com/parapsy.html](http://skepdic.com/parapsy.html) for details. This is the Skeptics dictionary and we’ll refer to it again when we learn about pseudoscience.
“Proof” in science is not the same as proof in a court of law. In fact, the word proof is not a good one to use while discussing science. A theory can never be established beyond question. When scientists say things like “I’m certain that this theory is correct,” or “That’s impossible” what they usually should say is “I’m very confident that this theory is correct,” or, “That’s not possible according to everything that I know.” No theory is ever proven. The best you can hope for is continued confirmation experiment after experiment.

Once a theory has been tested millions of times over decades or centuries it may be considered to be a law. Just as there’s no clear distinction between a hypothesis and a theory, there is no clear distinction between a theory and a law. In order of their certainty and reliability, they can be ranked from lowest to highest as hypothesis, theory and law. How sure can a scientist be? That depends on the individual, but I think you’d be surprised just how reliable scientific conclusions can be. Would you bet your life on the validity of Newton’s Second Law of Motion? I would. You do, too, every time you ride in a car or fly in a plane. They are designed using the law. (And when they fail at their tasks, it is not because the law failed but because some part failed or some human messed up in designing or assembling something. We can tell this, sometimes, by sifting through the wreckage and using the 2nd Law, and other laws, to figure out what did go wrong. So far, the 2nd Law of Motion is still in good standing, but many human errors and weather factors have been found to cause plane crashes.) You also trust your life to the Law of Mass Action in chemistry. Chemists use it when preparing medications, fuels, explosives, structural materials and Silly Putty.

Another example of a law that is almost certain is the 2nd Law of Thermodynamics. If you never heard of it, you still know it to be reliable. It’s the scientific law which concludes that if you leave a hot cup of coffee alone on a table, it will eventually cool down to room temperature. The 2nd Law of Thermodynamics is more sophisticated than this one example, of course, but it is called a law for very good reasons. If, when you find your abandoned, cold coffee, do you ever think to yourself that if you leave it alone for a while it may become hot again? That’s how certain scientists can be about some well-established laws.

To avoid another pitfall of scientific terminology, let’s make sure we’re clear on the word “law” in science. In everyday life, a law is a rule of conduct, created arbitrarily according to the whims of people. Some of those whims are almost universal and are very grave, such as laws against murder. Others are trivial but necessary, such as which side of the road one should drive a car on. However grave or trivial they may be, these are man-made laws. They say that if you perform a certain action, and you’re caught doing it, you will suffer some consequences for your actions.

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11 For some, the term law is reserved for successful theories that use very precise mathematical relationships. Because of these precise mathematical relationships, every measurement made is a test of the “law” so it may pass many tests, daily, for centuries. That makes for some well-deserved certainty. Some theories, like the Atomic Theory, are about as well established and as certain as any theory could be, but since it is not a mathematical statement, it is not referred to as a law.

12 Silly Putty is a registered trademark of Crayola, LLC. OK, so maybe you don’t trust your life to Silly Putty. Or, maybe someone has. I’d love to know.

13 Mathematically, it can be stated as $S = k \ln(\Omega)$ and the fact that $\Delta S \geq 0$ for a closed system. Learning just what $S$, $k$, $\ln$, $\Omega$ and $\Delta$ mean is the kind of stuff that makes chemistry and physics students’ brains hurt. A lot. We’ll see the 2nd Law of Thermodynamics in chapter 10.
The cartoon above is funny because it plays on the differences between the word law in science and in everyday life. Scientific laws are descriptive; they only describe what nature does and does not do in certain situations. Society’s laws are normative, referring to norms of behavior, or, in other words, how one should behave. A law against murder does not say that murder doesn’t happen, it only defines what murder is and what the penalties are if you choose to murder someone (or drive on the wrong side of the road…and get caught!). A scientific law cannot be disobeyed. If something is observed that seemingly violates some well-established scientific law, then that presents a challenge. If the law has been violated, then it’s time to reformulate the law (make a new theory) so that it works with the new data. Usually, however, the observation is mistaken or inaccurate and the law stands.

Finally, before we dissect the Scientific Method itself, I’ll say a bit about the experimental tests that are done. Our confidence in a theory is only as good as the tests it’s been subjected to. As stated in the definition above, the theory must be able to make predictions about experiments yet to be done. It’s a little more complicated than that, however, when we’re testing a theory about past events. This happens often in geology, astronomy, evolution and crime scene investigation. We just have to make sure that the theories are consistent with all the known, reliable data. But in a sense, predictions are still possible in Geology, etc. in that a theory can tell you what you’d expect to find if you go digging up some rocks somewhere. Although the rocks have been there a while, the data about them is new and provides a great test of a theory. Such tests are often called retrodictions rather than predictions, but the principle is still the same.

**Steps in the scientific method at a glance:**

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14 If you don’t think it’s funny, just play along, OK? Jokes are important tests of your understanding. If you “get it,” then you understand the concepts involved. Whether you find it funny is another issue. Think back to when you were very young and adults around you were making jokes about adult things. You didn’t understand the jokes because you lacked some crucial knowledge. Once you understood the jokes, you may have laughed or you may have been disgusted, but you would never be the same again. It is my hope that your education in science will be a similar experience. I can’t promise you won’t be disgusted at times.
1. **Question**— Form a question about causes and effects that lends itself to a physical answer. There are lots of important questions that don’t lend themselves to physical answers. E.g. love, ethics, religion and philosophy.

2. **Hypothesis**— Form a tentative answer to that question, an answer that CAN BE TESTED. This kind of answer is a hypothesis.

3. **Experiment**— Testing the hypothesis…see many details in the following pages.

4. **Theory**— when a hypothesis is confirmed, it becomes a theory, a working model of how some part of the universe works. A theory often involves several interrelated hypotheses that have been supported through experimentation or studies.

5. **Law**— a theory, or set of theories regarding related phenomena, that has been supported by many experiments and usually many years of success. It is precise and accurately reflects, to the degree tested, the behavior of some part of the universe. Laws are usually expressible as mathematical equations.

6. Revising or changing theories or laws...Ahh, but what if something NEW is discovered that violates an existing theory or law? Scientific laws are NEVER absolute. Everything is open to question, even a law that has been in place for 200 years.

7. **Repeat steps 1-6 as necessary, that is, FOREVER. Science is never “done” but is continuously being pushed to give us better and better descriptions of the physical universe.**
Diagram of scientific method in action

It’s very important to note that when one researcher does work, he or she may not perform all of these steps alone. The diagram represents, in a very simple way, how science proceeds over years or decades by contributions from the entire scientific community. Arrows show the usual way things go, but things don’t always proceed that neatly.
Overview; thinking about a scientific study or experiment

Before we get into the details about each aspect of the scientific method, let’s start with a brief summary of the main elements. Even without all the technical jargon and the finer points, these essential elements can help you understand what you read or hear about scientific discoveries. As a consumer of scientific information, you will likely get your information not from the primary sources (scientific meetings and journals) but from secondary or tertiary sources. For example, the New York Times may have a reporter at a medical conference and that reporter writes about one of the talks she heard. The article she writes is a secondary source. A reputable paper such as this will usually hire very specialized and well-educated reporters for such a task, but she can still miss a thing or two if she is not a true medical expert. If your hometown paper, assuming your hometown is not New York City, has a columnist or reporter who reads the New York Times article and writes an article based upon it, this article in the Podunk Weekly Standard would be a tertiary source. Unless the writer from Podunk is a medical expert, he is not likely to catch any mistakes or omissions in the New York Times article, and may add some errors himself. So, are you hopelessly lost when reading about scientific research? No, of course not! That’s the whole reason I’m writing this book.

What I am focusing on here are the crucial elements of the scientific method as the scientific community at large practices it. One of these elements can be placed under the heading of “communication”, which encompasses peer review, the critical analysis of one scientist’s work by another within the same field of expertise. Just what does one scientist look for in the work of another in order to determine whether the work is acceptable and credible? There are some basic criteria for good scientific work that everyone can learn to recognize. As you read about science in papers, magazines, blogs, etc. you ask yourself some of the same questions that scientists ask of each other. After some consideration, I’m sure you’ll agree that these elements are easy to understand. They are listed here with quick summaries and followed by more detailed descriptions.

1. **The Hypothesis.** This is the central idea being questioned in the scientific study or experiment. This is the why of the experiment. Why was it done? What did you hope to learn? Note that if the hypothesis is not confirmed or even supported, the experiment is not a failure. Some of the greatest experiments ever done showed that long-held ideas or theories were incorrect.

2. **Sample Selection.** How were the subjects to be studied selected? Why these subjects and not others? How many subjects is enough? Do these subjects adequately represent the class of objects to which the hypothesis applies? (E.g. Does a sampling of 1000 people in a Time/CNN poll accurately represent the opinions of the whole country?)

3. **The (true) Variable.** This is the physical condition (cause) that is being changed or monitored in order to see what effect it might have on certain observations. Occasionally more than one variable will be involved in a single study. Make sure you’re clear on what the variables are.

4. **The Control.** This is one (or more) of the experimental subjects that is not subjected to changes in the variable, and sometimes it is not exposed to the variable at all. The control is crucial because if there is no control, one can never be sure if the variable caused things to
change or if things would have changed without the variable. The word “control” is confusing, so it may help to think of the control in an experiment as the “reference” instead.

5. **Confounding Variables.** These are variables not under the control of the scientists but that might have an effect on the outcome of the experiment. These can be hard to find, even by scientists, but you can try by thinking, “What else may be affecting the results?”

6. **The Evidence.** Sometimes called the data, these are the observations and/or measurements that were made by the scientist(s) that conducted the study. To make communication easier and quicker, the evidence is often given in summary form, using statistics or graphs and charts if applicable. What is the evidence given in support of the experiment’s conclusion?

7. **The Error Analysis.** Sometimes called the uncertainty or “confidence level.” Every measurement has some degree of uncertainty to it because nothing can be measured with infinite accuracy. Every statistical average or trend is “fuzzy” because one can never have an infinite number of subjects to average. E.g. standard deviations analyze error. If you are reading about a scientific study and no error analysis is given, you are not being told the whole story. “Error” is uncertainty, not a mistake. This is, unfortunately, another bit of confusing terminology.

When reading an article about the latest medical study regarding what you should or shouldn’t be eating, consider the above points in evaluating both the article and the study itself. Likewise, when you hear a news story about the latest astronomers’ estimate of the age and size of the universe, ask yourself how accurately these numbers are known. In most popular media accounts of science it is point #7 that is usually left out.

**Details of experimental design and execution**

The above is a good checklist, but you do need to have a few more tools in your belt before you can really go to work asking good questions about scientific research or the knowledge that comes from it. So let’s begin by exploring how experiments are put together so that they can be effective.

**Types of experiments**

There are two broad types of scientific experiments that can be done; laboratory experiments and field or observational studies. In a laboratory (“lab” from now on), an experimenter can have almost complete control over the environment experienced by the subjects. That’s the whole idea behind the construction of expensive, state-of-the-art research facilities! A field study is done with subjects that either can’t be fit into a lab or can’t be controlled effectively (or ethically).

Chemistry is probably the best example for lab experiments. Chemists are very highly trained to use equipment and procedures that ensure that variables such as temperature, pressure and, especially, the amounts of materials, are precisely controlled. Since chemistry is ultimately dealing with matter at the molecular level, the amounts of materials used can be very small, even microscopic. So, it’s relatively straightforward to control such a small environment, which can be fit on a tabletop. Sealed containers can be made with temperature and pressure controls, light sources, magnets, electrical sources and all sorts of probes to measure what’s going on. It’s straightforward to make such isolation environments, but not cheap.
Geologists don’t have it so lucky. Say you’re a geologist who studies volcanoes (a vulcanologist). You can’t create volcanoes, so you have to travel to them, wherever they may be and whenever they happen to be erupting. You have no control over the environment. It may be on dry land or under a mile of ocean. So, you get yourself as close as you can to molten rock and poisonous fumes, hiking around on some of the most rugged terrain imaginable, making whatever measurements you can. And this has to be done very carefully so that you can live long and prosper.

Biology can be either experimental or observational. Even large animals can be experimented with in a large enough setting (like a zoo, for instance). There is always the problem, however, that conclusions drawn from a zoo experiment, say on behavior of the animals in response to some stimulus, might not be applicable to the same animals in the wild. Field biologists try to make observations on animal and plant populations in the wild and try to do so with a minimum amount of interference. There’s always the chance that the animal behavior witnessed is influenced by the presence of the researchers.

Field studies are also used when an experiment would be unethical. Take disease studies, for instance. Epidemiology is the study of diseases as they occur in populations of organisms, which can include people. Epidemiologists can study the course a disease takes; how fast it spreads, who gets sick and who doesn’t, where it spreads most easily, etc. They can do this retrospectively, for example the bubonic plague in medieval Europe, or as it happens, as in the seasonal and regional outbreaks of the flu. Like the vulcanologist, the epidemiologist has to wait for diseases to occur, they can’t cause them!

Or can they? In fact, in many controlled experiments people or animals are subjected to disease-causing agents and watched as they get sick (or not get sick). If the subjects are people, the diseases are not very dangerous. The common cold is a frequent subject of such experiments, the usual goal being to determine whether some medicine or practice will diminish the subject’s chances of getting the disease or the speed with which they recover from it.

Finer points can be made regarding the types of experiments (e.g. http://en.wikipedia.org/wiki/Experiment ) but we need not get into too much detail now. I’m stressing general understanding of concepts. Examples and exercises are crucial for understanding here, so as you read about other experiments and studies, you will get a better feel for the different varieties out there. From here on, I will use the term “experiment” to refer to an experiment of any type unless it is a pure observational study, in which case I’ll use the term “study.”

Hypotheses
There is not too much to elaborate on here except to emphasize that the idea you’re testing must meet some basic criteria to be consider a scientific hypothesis. It must link physical causes with physical effects; it must say this causes that. This and that must be objectively observable and, ideally, measurable.

A good example of an invalid scientific hypothesis is Sigmund Freud’s idea that the human psyche can be understood in terms of three interacting parts; the id, the ego and the superego. The id is responsible for our impulsive, hedonistic drives toward pleasure. The superego contains the highest moral principles, the rules that should govern one’s behavior. The

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15 Also spelled volcanologist, the word derives from Vulcan, the Roman god of fire, not the race of pointy-eared aliens from the Star Trek genre of television, movies and related fiction.
ego is the rational part of our psyche that is always striking a compromise between the id and the superego.

The trouble with the hypothesis of the id-ego-superego structure is that these three elements are not really identifiable physical causes for the physical effects we observe (i.e., a person’s behavior). How could we test to see if the id is the source of a person’s basest impulses? Can we take away the id and see if these impulses go away? Putting ethical problems aside for a moment, removing the id would be impossible since we don’t know where it is or how to remove it. So, we can’t do an experiment to manipulate the id variable. Could we do an observational study? What if we found someone who didn’t have an id? Could we then correlate the lack of an id with that person’s lack or possession of impulses? Well, no. If we don’t know what/where the id is, we have no way of knowing whether it’s really there or not. You might be inclined to say that if the person lacks impulses then it is obvious that they have no id. But that’s circular logic; you’re assuming to be true that which you are trying to test.

Virtually all of Freudian psychology is discredited now, because it turned out to not be scientific and, therefore, to not give a reliable, accurate model of human behavior. It has been replaced by much more concrete thinking about brain function in the form of modern neuroscience and more precise theories about emotions and experience where we don’t yet have the physical explanations that neuroscience provides. Still, Freud’s ideas held sway for a very long time, and still do in some minds. That’s probably because it was the first attempt at a scientific theory of the mind and it sometimes does provide insight into human behavior.

There are some modern experiments that are now showing support for some of Freud’s ideas, in the form of certain areas of the brain that handle certain emotions and impulses in the case of the id and moral reflection in the case of the superego. Ultimately, though, Freud’s original ideas were too vague to be real scientific hypotheses. So, we thank Freud for giving psychology a great start, but we move on and improve on his pioneering attempts. That’s what science does.

Sample Selection
Any experiment must have subjects to work with. These subjects must represent the class of objects that a theory-in-testing refers to. Usually, an experiment can’t be done with all of the objects of interest, so a smaller group of similar objects must be used, a sample. Choosing subjects is critical to the success of an experiment and can often be the most difficult part of experimental design. I’ll use a couple examples to illustrate.

If you have a hypothesis about some nutrient and its effect on peoples’ health, you should test that hypothesis by setting up an experiment where some people get the nutrient, some others get more or less of it, some get none, etc., and seeing what effect the nutrient (your variable) has on their health. Let’s say the hypothesis is that vitamin R, in the proper amount, is essential to a properly functioning sneeze reflex. Here’s the problem. There are about 6.8 billion people on this planet. To know the answer, really know it, you have to know that the results of your experiment can be generalized to the whole population of the world. Your experiment, or any conceivable experiment, will have to use a small sample of the world’s population. You should, therefore, have a sample, a group of test and control subjects that represents the world’s population. You would have to have a mixture of races, ages, genders, lifestyles, diets and

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16 http://www.census.gov/ipc/www/idb/worldpopgraph.php That is a staggeringly large number. It is twice what it was when I was born in 1965, a mere 46 years ago. Some feel that this rapid growth in population is the single biggest environmental and political issue looming for our future. I agree.
locales. Not easy, is it? No, it’s very difficult indeed. If your experiment is performed in mainland China on native Chinese people, all you really know is that your results probably apply to Chinese people. Do Scandinavians also need vitamin R for proper sneezing? You really wouldn’t know until you, or perhaps your collaborator, Dr. Shnarghessrussmen in Stockholm, tests the theory on some Scandinavians.

What if you can’t actually experiment on the subjects you’d ideally like to study? You might have resort to using a substitute. In medicine or biology, such substitutes are called model organisms. A good example is the laboratory mouse that is often used to test the effectiveness and safety of medicines before experimentation with humans can ethically begin. A mouse is not a human, but they are alike enough in many respects to get some meaningful and transferable data. Other model organisms in biology and medicine include dogs, primates and tissue samples. A more straightforward model approach is used in engineering, where model buildings and bridges might be used in an experiment on the earthquake worthiness of some designs.

So, when an experiment shows that a certain food additive, like an artificial sweetener, gives rise to cancer in laboratory mice, the most we can really know is that the sweetener gives cancer to mice. It is a large step to conclude that the sweetener might cause cancer in humans. It is a large step, but not necessarily a ridiculous one. After many years and many experiments, biologists and biochemists have amassed a great deal of knowledge about how mice are like us and how they are not.

More about Models
There are really two types of models used in science. The ones mentioned above can be considered experimental models. Theoretical models are different and more abstract. Consider a globe that represents the Earth. It is, in many respects, like the Earth; the distances from place to place, the orientation of the continents, the connections among the oceans. It models only the geometry of the surface features of the planet. It is useless when considering the chemical properties of the oceans and atmosphere or the physical properties of the molten interior regions. Likewise, a toy car is a good model to consider when you want to experiment with the geometry of an architectural design for a garage or driveway, but it’s likely to be less useful in crash testing.

Models are used both in theories and as subjects of experiments. In a theory, a model is a simplified version of a real subject, not a substitute for it as with an experimental model. So the globe mentioned above is a very limited theoretical model. The most abstract, but sometimes the most powerful type of model, is the mathematical equation. Letters in a mathematical equation are stand-ins for numbers that aren’t known yet. An equation shows how the quantities are related to one another. Consider a simple equation, \( y = 2x \). This equation states that whatever value \( x \) might have, the corresponding value for \( y \) is always twice as great. Now, \( x \) and \( y \) don’t really mean anything in and of themselves until we attach some meaning to them. So far, \( y = 2x \) is just pure mathematics. Let’s attach some meaning to these letters. Let’s let \( y \) represent the number of legs in a room. Let’s let \( x \) represent the number of people in the room. Now, \( y = 2x \) is a good model for the relationship between the number of people (\( x \)) and the number of legs (\( y \)). Scientists will often use letters that are easier to remember, so they would likely use the equation \( L = 2P \) instead of \( y = 2x \). Note that this model, \( L = 2P \), is ideal. It doesn’t account for the fact that some people might have lost a leg, or two, due to injury or disease, or any other situation where

\[ \text{footnote 17} \]

I refuse to enter the quagmire of whether animal experimentation is ethical or not. That debate already fills countless books. Let’s keep focused, here. That said, however, don’t stop reading these footnotes!
someone may not have exactly two legs. For beetles, \( L = 6B \) (\( B = \) beetle!) and for spiders, \( L = 8S \) are ideal models.

What’s so powerful about mathematical models is that they can be tested by just scribbling down stuff on paper (well, and thinking about mathematics) or doing calculations on a computer (often referred to as computer modeling). One can compare the results of the calculations against known facts and tell how good the model (and the theory based on that model) works. You don’t even have to do a specific experiment to gather new data. You can use old data and just see if your model works with it. This is what Isaac Newton did with his theory of gravity. He tested his mathematical model on what was already known about the orbits of planets in the solar system. Oh, and, by the way, his model passed the test!

In most of the natural sciences, the data gathered are measurements, that is, numbers. If you have numbers to work with, mathematics is sure to follow. There is a term, hard science, that refers to physics, chemistry, geology, etc., wherein the data are very numerical (“hard” in the sense of solid and precise) and, thus, the theories are very mathematical. Many people, perhaps including yourself, are not fond of math because you find it very difficult to do. If that is the case, the term “hard science” takes on a meaning very different than what the term originally was meant to convey. I want you to consider the opposite. The “hard” sciences are easy compared to the social sciences like psychology and sociology because the data you obtain in the hard sciences are very clear. In psychology, you have daunting tasks like trying to assess a person’s happiness or sense of danger. How happy is the patient? 23? 42? 87? Even with questionnaires and psychological testing it is impossible to get such precise and reliable numbers. In my opinion, that makes psychology really hard, that is, difficult. Physicists have it easy with electrons; they are all identical and have well-known properties such as mass, electric charge and so forth.

Coming back to theoretical models, I’d like to emphasize once again that they are idealizations and one has to be very careful to not confuse them with the real thing. Here’s a story that serves as a cautionary tale. In most of my research, I do simulations (computer calculations) that model the behavior of atoms inside of solid materials. Now, it takes a lot of physics to do those calculations, but it always involves using a theoretical model to estimate the forces between the atoms, etc. While I was working as a researcher at Rutgers University, I was looking at the computer screen at a simulation of tungsten oxide. I was puzzled by the behavior of one of the tungsten atoms, represented by a blue ball, and why its position was not what I expected it to be. My boss, Steve Garofalini, looked amused when I spoke of the tungsten atoms and the oxygen atoms. He said, “What tungsten atom?” I pointed to a blue ball on the screen and said, “This one.” He said, “That’s not a tungsten atom, that’s a blue ball, and those aren’t oxygen atoms, they’re red balls. Don’t ever forget that.” I won’t, Steve.

**Variables and Confounding Variables**

A variable in an experiment is a supposed cause for some physical effect. In the alcohol and orange juice story earlier in the chapter, the variables being studied were alcohol and orange juice. They were possible causes for the effect of intoxication. Keep that cause and effect notion foremost in your thinking because that is what science is ultimately trying to figure out. The term “variable” is used when describing a possible cause that is explicitly being tested (alcohol and orange juice).

Other possible causes for intoxication were also considered; contaminants on the drinking glasses, the ice, the phase of the moon, short-term Federal Reserve interest rates, etc. These
 weren’t explicitly tested in the experiment, which only had subjects drinking pure orange juice to see its effects. Since they weren’t tested explicitly, these extra possible (even if implausible) causes are considered to be **confounding variables**. The term is a good one, because the possible existence of other causes you haven’t checked out is, well, confounding! If you can’t eliminate these other causes, either by explicit testing or inference from other known facts (such as the fact that you have never known ice to have any intoxicating effects) they suspend your knowledge in a state of confusion and uncertainty.

When I was about fourteen, and just starting to grow a fine, fuzzy beard, my grandfather asked me if I started shaving yet. I told him I had not. He immediately warned me to never start, because the shaving would just make my beard grow. He assumed that was something that I wouldn’t want. (He was wrong.) Well, thought I, I’ll shave, then, because I want to grow a beard! But then I thought that, if shaving caused beard growth, and if no man had ever shaved, throughout the history of human race, then there would be no beards. Furthermore, since I had not shaved yet, what caused the very little growth I had at that moment? How could I tell if shaving really caused beard growth, or even enhanced it? I soon concluded that I could not possibly experiment on myself to find out. Why? Confounding variables. Though I could manipulate the shaving variable, I had no control over the passage of time, which was working with my genes and my hormones to cause beard growth; the genes and hormones and time were all confounding variables. Even if I decided to experiment on my two younger brothers (evil scientist that I am) I still wouldn’t know, because some of their genes are different from mine. If I made one shave and he grew a beard, how would I know if it was due to the shaving or due to his genes? If I made the other not shave and he did not grow a beard, was it because he didn’t shave or because he would never have grown one in the first place? Genes play a big role, as evidenced by the relative thickness of beards in the various races (e.g. Asians are light-bearded while Caucasians tend to have heavier beards). They both ended up shaving and having some beard growth. (Not as much as me, but maybe I shaved more?) Ahh, confound it! I’ll never know if my grandfather was serious or if he was pulling my leg. Thanks, Grandpa!

**Control**
The control or controls in an experiment answer the question, “Compared to what?” In Suzie’s Miracle-Gro experiment, the plants to which she only gave water were the control subjects, or controls. If we want to say that Miracle-Gro speeds growth and promotes health in plants, then we have to have a comparison group to point at and say, “See, these didn’t grow as well.”

In such straightforward experiments, the control is easy to arrange and easy to understand. In many field studies and epidemiology, controls are very hard to come by and thus conclusions are more difficult to establish. That is because you can’t manipulate the situation, only observe what’s happening. Furthermore, you don’t know everything about your subjects. If you are tracking a flu epidemic, for example, you might only have data on how many patients were diagnosed with the flu by physicians in certain areas. There are undoubtedly people who got the flu and never sought medical attention. Some who did seek medical attention may have been misdiagnosed. You might have data on what their occupations are, but you will not know who came in contact with whom. Usually, all that’s known is whether the person works around a lot of people (retail, teaching, health care) or not (construction, novelist, hermit). Good science is always hard work, but sometimes it is nearly impossible given the circumstances. Sometimes it is impossible.
If the subjects of the experiment are humans, or perhaps even intelligent animals, there can be a problem once the subjects realize that they are in a particular part of an experiment. Their behavior may change and therefore disturb the results of the experiment, especially if the experiment has to do with measuring behavior, attitude or opinion. The remedy for that is the blind experiment, wherein the subjects don’t know if they are being subjected to a variable or not. Commonly used in medical studies, it goes something like this.

In this scenario, you are testing a new herbal tea that claims to have a calming, relaxing effect on people. At first glance, some might think that all you have to do is give a bunch of people the tea and ask them if they are relaxed after drinking it. Some, but not you, since you know you have to have a control group drinking another herbal tea, regular tea or maybe even hot water. That way, you have a comparison group to see if the new tea really does the job better than other products. That approach works just fine if you are testing fertilizers on plants, but the problem with your subjects is that they know what’s happening to them and that can alter their perceptions and judgment. If you tell them you are testing an herbal tea for its relaxation effects and they love herbal teas, they may be biased into finding this tea particularly relaxing. They may also be biased in favor of your tea if they find you charming, trustworthy or good-looking. The reverse may also be true and they may report that the tea does not relax them because they don’t like you or are philosophically opposed to herbal teas. What can the noble scientist do?

What you have to do is trick your subjects. You have to make it so that they are “blind” to what’s happening in the study. So, you can have several groups drinking different teas, water, etc. but you can’t tell your subjects what they’re drinking. You can tell them that you are testing a new drink that is supposed to have relaxing effects. In this scenario, any drink other than the herbal tea you are testing is called a placebo, a substitute for the item you are testing, and furthermore, a substitute that is supposed to have no effect. Still, the subjects might be biased. If they don’t know if they are drinking the test beverage, but they expect their drink to be relaxing, then they can mentally fool themselves into relaxing even if they are drinking water. This is called the placebo effect, when a subject reacts to a placebo in a way similar to the actual active ingredient. It’s a very common effect, and sometimes physicians actually use it by giving an inert substance (a “sugar pill”) to a hypochondriac patient who miraculously gets better (has less pain, more energy, improved mood, etc.).

What can you do about this? You have to get trickier, still. (Science can be fun!) You’ve already seen the value of not telling the subjects what drink they receive, but you can also avoid even telling them what you’re testing, exactly. That way, the subjects don’t have any expectations as to what should be happening to them, at least, they won’t have any expectations that might skew their reactions. A clever trick, for example, would be to tell them that you are testing a tasteless ingredient that might improve their eyesight. That way, whatever the subject might drink, he will not know if he is getting the ingredient or not, or even how its supposed to affect him! During the course of a pretend “eye exam” you can ask them questions about their state of relaxation, measure their heart rate, etc. (You are tricky, aren’t you!) You ignore the other data and just focus on what they drank versus their states of relaxation and you have the data that you need to form some conclusion. You have just performed a very much-improved blind experiment. They are blind to both what they are receiving and what you are looking for.

**Double-blind**

On second thought, take a look at the other data. You might have just stumbled upon a remedy for bad eyesight!
There might still be a problem, though. What if you, the researcher, are biased? This might be true if you own the herbal tea company or are getting paid by it. It is in your financial interest to get experimental results that support the claims made by the tea company. Or, you may believe for some reason that the herbal tea will (or won’t) work. You may be a scientist, but you are also a human being! What can be done, now?

You have to trick yourself! You have to set things up so that not only do the test subjects not know what they are receiving, but you (or other scientists making the observations; let’s call them the observers) don’t know which subjects are receiving which beverage. How is that possible? What you have to do is have the subjects drink their beverages out of the sight of the observers and instruct them to not say anything to the observers about what they drank (what it tasted like, if it was hot or cold, etc.). Perhaps we could have an independent crew of beverage handlers who know what beverage to give which subject, but these beverage handlers can’t be allowed to communicate to the observers. That way, the observers just record their data objectively and don’t exaggerate or misrepresent the responses of the subjects. Even if the observers wanted to cheat, they couldn’t.

This is called a double-blind experiment; neither the subjects nor the observers in direct contact with the subjects know who is getting what substance. This is often done in medical studies. One set of patients is given the real drug, let’s imagine a round, green pill from a jar marked “A,” and the control group is given an identical pill, a placebo, from a jar marked “B.” Somewhere, a secret document is kept in which the contents of jars A and B are recorded along with information about which patients are receiving which pill. That document is kept secret, from the observers and the subjects, until the tests are over. Care must be taken so that no one detects the secret prematurely. For example, observers should require the subjects to swallow the pills whole under careful supervision. Otherwise, the subjects might detect a bitter or sour taste that may hint at the presence of a drug and not merely the sugar or cornstarch in a placebo. It can get very tedious and complicated. Again, that should be no surprise. Good science is hard work.

Error Analysis

In science, and only among scientists, the word error has a very peculiar meaning. It does not refer to a situation where a scientist drops a beaker, misreads a thermometer, jots down the wrong number in her notes or gives the wrong drug to a patient. These situations are referred to as mistakes, negligence or, if intentional, fraud. Error is something that all scientists, even the best, experience. Error has to do with the fact that any measurement that you can conceive of cannot be 100% accurate. Error is another word for uncertainty. Scientists must always be aware of how accurate their measurements are, and they report these inaccuracies in their work in a process called error analysis.

Consider the odometer on a car. In most cars, the odometer is digital and tells you how far you’ve driven to the nearest tenth of a mile. How far is it from here to grandmother’s house? Say you set the trip odometer to zero at your house and drive to grandmother’s. Over the river and through the woods, your car dutifully measures the distance along the way and when you arrive the odometer reads 145.3 miles. So, how far was it? Exactly 145.3 miles? Maybe, but since the odometer rounds off to the nearest tenth of a mile, it would read “145.3” even if the distance were as small as 145.25 or as large as 145.349999. (At 145.2499999, it will round down to display “145.2” and at 145.35, it will round up to display “145.4”). Essentially, the distance is uncertain by an amount that could be up or down by 0.05 miles (half of a tenth of a

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19 Or to the nearest tenth of a kilometer if you live in an enlightened country that uses the metric system.
mile). So, if you really wanted to be honest and thorough about how accurate your knowledge is you would have to say that the distance to grandmother’s house is 145.3 miles give or take 0.05 miles.

Who cares? All you’re thinking about is grandmother’s cooking and the lovely Thanksgiving dinner that awaits you; the turkey, the pumpkin pie, the stuffing, the lutefisk! A scientist wouldn’t care either, unless the distance was important to his research. In that case, he would have to worry about this and report the uncertainty, the error, to his scientific community. That way, they know how much confidence they can place in his data and, more importantly, any conclusions that he might draw from his data.

It can get downright grueling to assess the total error associated with an experiment. There will be multiple sources of error and the scientist has to figure out how the errors build up in the final calculation of any results. Consider a chemist who during the course of an experiment must measure the temperature of a liquid, its acidity (referred to as “pH”), its volume and or mass, maybe its viscosity (how thick it is; ketchup is highly viscous and water has low viscosity), etc. All these measurements have error and they all affect the accuracy of any results that are reported. Just how to go about estimating the total error we’ll leave to the experts, but let it suffice for me to say that if he doesn’t do it properly his results will not be well received by his peers, and probably won’t be published in a reputable scientific journal until he adds such an error analysis.

Perhaps the clearest error reporting you’ll see in the news are the “plus or minus” percentages that accompany political or public opinion polls. The Gallup company has been known for decades in American politics and newsgathering. In a recent poll about approval of President Obama’s job performance, it was concluded that 56% of adult Americans approve. The published results of that study come with a disclaimer at the end. “The latest weekly average results are based on telephone interviews with 3,628 national adults, aged 18 and older, conducted July 20-26, 2009. For results based on the total sample of national adults, one can say with 95% confidence that the maximum margin of sampling error is ±2 percentage points.” So, maybe as much as 58% (56% + 2%) or as little as 54% (56% - 2%) of Americans approved of Obama’s performance during that week.

What’s being reported here is very subtle, and, I must add, very scientific and professional. The pollsters know exactly how many of the people they asked approved of Obama and how many didn’t, so where’s the error? It is, as they write in their disclaimer, in the sampling. It’s our fundamental question about inductive reasoning all over again. If you want to know, really want to know how many Americans approve of the President’s job performance, you should ask everyone and report the results. Logistically impossible, and outrageously expensive, that would never be done. Furthermore, it would take so long that you couldn’t have weekly polls! That might be a good thing, but I digress. Again. Anyway, instead of asking everyone, they asked 3,628 American adults, a bit more than one in every million Americans. They take care to select this sample to represent the American people. It has a representative percentage of the various races, ethnicities, regions and incomes. But they know they can’t get it perfect (0% error) with a sample drawn from the total population. How they arrive at 2% is fascinating but very complex. They have a small army of senior scientists and experts that make their life’s work doing this sort of thing.

Sometimes scientists use visualization to convey error, especially in graphs. Scientists like graphs, but scientists love graphs with what are called error bars. The actual measured value, or calculated value of some quantity in the experiment is represented by a dot on the graph.
Then, bars above and below show how uncertain each dot’s actual location might be. It could be as high as the high bar and as low as the low bar. Of course, smaller error bars (less uncertainty) are better. Large error bars can prevent one from accurately assessing the behavior of the data. It can be so uncertain that you might not be able to tell whether the trend is increasing or decreasing.

The bottom line is that if you are not being told what the error is in an experimental conclusion an important piece of information is left out. Think of an election poll. If Gallup states that Jerry Mander is leading Chad Hangar 54% to 46% in the Podunk mayoral race, you might be tempted to think that Mr. Mander has things wrapped up. But when the good folks at Gallup tell you that the margin of error for this poll is plus or minus 10% (mathematically written as ± 10%), you realize that the poll really doesn’t tell us much; it’s still a toss-up as far as they can measure.

**Error Bars**

In the top graph, the data have large error bars, so that either line might represent the actual trend in the data, although the green one looks a bit better.

In the bottom graph, the error bars are much smaller and the pink line can no longer be used to represent the same data. Smaller error eliminates some conclusions that one might draw from the data.
When thinking about error, realize also that there are many different types of data from different types of experiments. Some yield statistical results, like surveys and medical studies, while others provide more direct data, such as a photograph of a newly discovered asteroid. All have inherent uncertainty. This is obvious in the case of statistical results, which may be accompanied by terms such as “confidence interval,” standard deviation, P-test, T-test, and variance. I will not go into a discussion on statistics in this book. There are well-established and reliable methods for assessing the amount of error and confidence in statistical results. How about more direct data? Error is subtler for, say, a photograph, but think about how clear the photo is. Is it crisp or fuzzy? There is always uncertainty in any scientific knowledge.

**Correlation or Causation?**

There is a natural question that arises from all statistics-based experimental results. It often even comes into play in more direct experiments. A certain observation may always be associated with a variable in an experiment, but does that mean that there is necessarily a cause (variable) and effect (observation) relationship between the two? For some things, it’s that easy and obvious; rain and clouds, for instance. Whenever rain occurs, there are clouds either directly above or very near by. Rain is said to be correlated with clouds; they go together. Do clouds cause rain or does rain cause clouds? Well, additional data, that clouds don’t always come with rain, helps us greatly in identifying cause (clouds) and effect (rain).

Consider a classic and amusing example of some reversed thinking, though. Fire fighters are seen around fires, and the larger the fire, the more fire fighters there are likely to be. If you knew nothing about fires and fire fighters, you might very logically infer that fire fighters *cause* fires. That sounds silly, but what if the data you were looking at had nothing more than information on

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20 You’re welcome.
how large the fires were and how many fire fighters were on the scene? You might make a conclusion that actually reverses cause and effect. The caution here is that correlation does not necessarily imply causation. Other data that you know clarifies the relationship; fires usually precede the arrival of fire fighters, for example. When new scientific observations and experiments are performed, however, the scientists, by definition, do not know all the data, so it’s easy to be led astray.

Consider a good, recent example. In 1999, researchers at the University of Pennsylvania (a very good school, by the way) published a paper in the journal *Nature* (perhaps the best scientific journal in the world) that strongly implied a link between parents leaving lights on in their infants’ bedrooms and the development of nearsightedness (myopia) in the children. The press immediately ran wild with cautions about leaving the lights on in baby’s room. There are nothing like parental fears to sell a story in the media!

I’ll go right to the punch line. No, lights left on in baby’s room do not increase the chances of myopia. Larger follow-up studies by other scientists showed the true cause-and-effect relationship, genetics. Nearsighted parents are more likely to have nearsighted children. Nearsighted parents also benefit from bright lights that improve their ability to see well, an ability they are going to want to have when rushing into a baby’s room to respond to crying in the middle of the night. The original study never gathered data about the parents’ eyesight, so they missed something important.

How stupid could the original researchers be? As it turns out, they are pretty smart and they knew they were making a very preliminary observational study that simply suggested that further studies should be done. (And they were!) The original researchers were not being rash. They had a very good reason for suspecting that lights left on might be a problem. They knew that farmers raising chickens often leave the lights on to speed the growth of newly hatched chicks. That rapid growth, however, leads to their eyeballs growing a bit faster than their skulls, which leads to elongated eyeballs. Elongated eyeballs are the #1 cause of nearsightedness in humans. Now, that doesn’t sound so stupid, does it? They asked a logical question that they thought might have enormous implications for the eyesight of billions of people.

When data started emerging in the 1940s and 1950s that suggested a correlation, and a very strong one, between cigarette smoking and lung cancer, the tobacco companies in the U.S. were very quick to point out that correlation does not imply causation. Still, when the correlations are so strong and so enduring, it’s tempting to say that cigarettes cause lung cancer. What’s needed to sort it all out is, of course, more data to establish a causal link between cigarettes and cancer. That’s the subject of the next section.
Another example of correlation without causation. There is no reason to suspect that a large number of pirates would lead to global cooling. A mechanism was proposed, indirectly, by stating that “pirates are cool,” but this was meant in a swashbuckling, personality way, not thermodynamically. (Figure from Wikipedia, http://en.wikipedia.org/wiki/File:PiratesVsTemp_English.jpg but the original concept is from Bobby Henderson, http://www.venganza.org/.)

*Mechanisms in theories*
A clear understanding, or even a clear hypothesis, about which is cause and which is effect can be gained by having a **mechanism** in your theory. A mechanism is a known process that can connect a variable (cause) and an observation (effect). For cigarettes, lots of data started flooding in that strengthened the link between their use and lung cancer. But a mechanism was still lacking. How could cigarette smoke cause lung cancer? It was known as early as the 1920s that cancerous tissue had DNA that was different from that of the normal tissue around it. In the 1950s, a link between cigarette smoking and lung cancer began to receive serious scientific scrutiny. It was quickly established that there are many chemicals in cigarette smoke that are mutagenic (cause changes in DNA) and therefore might potentially be carcinogenic (cancer causing). That was a mechanism that converted a simple correlation to a very likely causation. In the 50 years since then, related support research has established beyond any scientific doubt that cigarette smoking causes lung cancer. In fact, it is thought to be the cause of 90% of all lung cancer.

A mechanism is certainly helpful to a theory but not necessary for a theory to be successful. When Gregor Mendel established the idea of genes as units of heredity, he had no idea what these genes might be. For decades, the field of genetics developed, establishing rules for how genes interacted with one another or combined to lead to the rules of heredity for blood types, eye color, etc. The theories of inheritance were successful in predicting the results of
experiments, but there was no mechanism, no known way of how the genetic information was passed from parent to offspring. Genetic theory was strengthened, however, in the 1940s when it was established that genes were composed of DNA.

A very precise law, the Law of Gravity, still has no definite mechanism. All we really know is that all bits of matter attract one another and this causes apples to fall and planets to orbit the sun. But, we still don’t quite know how gravity accomplishes its task. We can predict these forces and motions with astonishing accuracy. But the theory, although successful, is incomplete without a clearly understood mechanism. Ultimately, all we really know for now is that gravity just “is.” We’ll learn more about gravity in a later chapter.

Falsification or Confirmation?
At this point, I think we’ve picked apart the major worrisome aspects of scientific theories and experiments. There’s a lot of detail in the preceding pages, but they’re just that, details. Make sure you focus on the big picture. An experiment is designed to test a hypothesis, and scientists have to go to great lengths to make sure every angle and loophole has been considered and accounted for. I’ve just given you an overview of some of the main problems associated with most experiments and the techniques used to overcome those problems.

What is most important at the conclusion of an experiment is to assess one thing; does it confirm the hypothesis or falsify it? An experiment is considered successful if does either, because the goal of experimentation is not to show that a particular hypothesis is true, but to arrive at the truth about that hypothesis, and that truth might just be that the hypothesis is false! Regardless of whether the hypothesis receives confirmation or falsification, the next step for a researcher is to make others aware of the experiment and see if its results are convincing. Science assumes that two heads are better than one, and a few thousand are better than two. That’s why it’s essentially that experimental results are made widely known, so that others can find flaws in the experiment, suggest improvements, repeat the experiment and maybe, just maybe, recognize the genius and technical mastery of the experimenter.

After the Experiment
Accountability
Every scientist is accountable for his or her work. If you’re a scientist and you do good work you deserve the reward of public admiration for your industry and cleverness. If you do work that is less than good, the scientific community demands that you admit your shortcomings and correct them if you want to improve your standing in their eyes. If you fail to address the shortcomings in your work, your scientific colleagues will eventually ignore you; listening to you or reading your work becomes a waste of time for them. It’s important for me to be especially clear here. A person doing substandard work in science is cast out of the scientific community, or never let in in the first place, for doing bad science, not for ideological, cultural, political or other reasons. At least that’s the ideal, and so it is in other professional fields. Take Olympic sports for example. In the high jump competition, all that should matter is how high you can jump. Have athletes been excluded for political or ethnic reasons? Yes. Is it wrong to do so?

21 By “scientist” here I am being very general in describing someone who is trying to discover things about the physical universe. A “scientist” need not have any special education or qualifications. A classic example is Michael Faraday who was one of the greatest scientists.
Yes. So it is with science, where some great work has been wrongly excluded from the scientific community, at least for a while. Scientists are humans but they aspire to maintain a process that is superhumanly fair and honest. To be this fair, you have to be very open with information.

Open communication with the scientific community and public

I opened this chapter with a semi-fictitious account of little Suzie and her plant fertilizer project for the elementary school science fair. Why should she present her project to an audience? For her education and her personal growth it is important that she learns to speak to others and communicate complex ideas to them. Why not just present her project to the teacher? Well, strangers like me are a larger challenge for Suzie, who may be shy. But there are a couple more reasons why she should present her work to the outside world. Isolated, alone, without a teacher or parent nearby to support her, Suzie must be able to show that she understands the ideas she is presenting. She must also be accountable for her work and stand up to criticism of her methods and results. That is crucial in the real process of science. That is what professional scientists do.

Open communication in science takes place primarily in the pages of scientific “journals” or at conferences and meetings where scientists gather to talk about their work. The best journals and conferences are “peer reviewed,” which means that for a paper to be published or a talk to be given it must first be reviewed by a panel of experts and accepted. It may be rejected but with some suggestions for improvement. With the noted improvements it may then be accepted. This peer review is conducted by, well, peers—people that have published work in the field before. This is done for free by the peers. When I submit a scientific manuscript, I know that it’s going to end up on the desks of some other scientists who will have to make time in their schedules to read and critique my paper; almost always anonymously. I do the same for them. The editors of the journal or the organizers of the conference then collect these reviewers’ reports and decide whether the work submitted is worthy of publication or presentation. It is a very proud moment when a scientist receives a notice that his or her paper “is accepted.”

Once published or presented, the scientific work is then subjected to another round of scientific scrutiny. Just as when Suzie is done making her science fair presentation and she nervously awaits the judge’s questions, a scientist who has just finished a talk or published a paper braces himself for the questions and criticisms sure to come. The dialog then begins, either in a series of papers and letters or a discussion in the meeting rooms at a conference. Peer review is an essential part of science.

Although today it is uncommon that an untrained person will publish scientific research, it does happen. Note that when I submitted my scientific work throughout my career, the journals or conferences I sent my papers to never asked if I had a Ph.D. or even a B.S. or even what field of study I was trained in. They don’t care. What they do care about is the quality of the work that is submitted.

Secret Science?
I suppose it is possible for science to be done in secret. Certainly one could perform experiments in one’s own secret laboratory and satisfy one’s own curiosity and one’s own standards for quality work.
There are and have been some very big scientific research projects that have been done in secret by governments, businesses and even, temporarily, universities. Even in these cases, however, there is either a limited community working together or the secrecy is maintained for a limited time.

The Manhattan Project is a classic example of very big research being done with great secrecy. This was the initiative undertaken by the U.S. government in 1943 for the purpose of trying to create an “atomic” bomb and thereby gaining the upper hand from the Nazis who were also working on the idea. World War II may have turned out very differently if the very large, very secret Manhattan Project did not take place. It was very secret, and none of the results gathered in their research were communicated to the greater scientific community or the public. Still, there was a community of scientists within the project and they critiqued each others’ work. Also, in the end, much of what they learned became known to other scientists after the war.

A business developing new technology might have its scientists working in secret so that the company can secure a patent on the technology. Then, they can publish the results of the research. The patent papers actually will contain the information that other scientists would need to know the secrets. But the patent gives the business behind the invention what it needs; the secret may be out, but no other company can make or sell the technology without the permission of (and usually payment to) the business that developed the technology.

Since the focus of this book is the scientific method as commonly practiced, though, I’ll stick to describing the usual practice of science as a public enterprise, giving (eventually) all the knowledge to the whole world. Patents and secret military technology just delay the inevitable public knowledge of the science within.

**Universality**

The goal of science is to describe how the universe works. That’s the same universe for you and someone in Botswana. As theories are created, tested, modified and merge, they become more universal, applying to ever-wider classes of objects: The novel idea that certain proteins were the cause of the disease scrapie in sheep and goats was generalized to include the same sort of cause in mad cow disease in cattle and, later, Creutzfeldt-Jakob disease in humans. What emerged was a new concept of disease caused by prions, pure proteins that are neither living matter nor toxins in the usual sense. In physics, an explanation for why apples fall to the ground merged with an explanation for the moon’s orbit around the Earth and an explanation for the Earth’s orbit around the sun. What resulted was Newton’s theory of universal gravitation, which describes how every object in the universe is attracted to every other.

If theories were only tested by a select few scientists in a select few locations, it is unlikely that we would get such broad, universally applicable results. Free and open communication in science guarantees that all people will benefit from scientific knowledge and, just as importantly, that all people can contribute to building the knowledge and improving our understanding of our common universe.

It is tempting to imagine all of our current theories merging further still until they are all included in a “theory of everything.” Such a theory would explain everything from the tiniest

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22 In modern usage, we would say “nuclear bomb” for reasons that will become clear in a later chapter where we go inside the atom.

23 I just picked an arbitrary and, to me, exotic locale. If you are from Botswana, reread the sentence above and replace the name of your home with “Paramus, New Jersey.”
subatomic particle to the largest cluster of galaxies and on to why we fall in love. Needless to say, we’re not there yet. Some regard that possible theory with wonder and hope. Some fear it more than anything else. No matter what side of this you’re on, the eventual emergence of a theory of everything is the logical conclusion of the assumption that science makes when it insists that all our scientific knowledge be self-consistent. What we know about human emotions and volcanoes must be consistent, on some common levels, with what we know about bacteria and hydrogen.

Before we can get on to what we know, and how we know it, however, we need to put science in its place, both in history and in relation to very closely related topics, mathematics and technology. I’ll summarize the first part of this book with an overview of scientific thinking itself. Then, in part II, you’ll be introduced, or reintroduced, to the big ideas in the natural sciences. These are the ideas that every professional scientist keeps in the back of his or her mind when trying to connect the dots and get the big picture. These are also the ideas that you need to understand appreciate the picture that emerges when they connect the dots.

What it all means to you

Quote:
“…Creating a new theory is not like destroying an old barn and erecting a skyscraper in its place. It is rather like climbing a mountain, gaining newer and wider views, discovering unexpected connections between our starting point and its rich environment. But the point from which we started out still exists and can be seen, although it appears smaller and forms a tiny part of our broad view gained by the mastery of the obstacles on our adventurous way up.”

Albert Einstein and Leopold Infeld

I love the quote above because it gets at the real wonder of science. That real wonder is not an accumulation of facts but the development of a perspective that lets you see your world differently than before.

As you reflect on this chapter and as you read the rest of the book, I don’t want you to misunderstand my intentions. I do not intend for you to think of me as bragging: “Science is so wonderful and powerful and I, being a scientist, am so intelligent and learned that you should worship me and trust my words.” While that is a response I could possibility live with, it is ultimately unproductive for you. Science is a process of gaining knowledge about the physical world. It is a way of thinking that you can, and should, incorporate into your daily life. By thinking scientifically you empower yourself to better understand your world. You empower yourself.

In the rest of this book you’ll learn, or relearn, some of the fundamental aspects of the major branches of natural science. It is my fervent hope that while reading you think not “Dr. Boucher is sooooo smart, and I’ll never learn this” but rather “I now understand the big picture about this and it all makes more sense now.” The nitty, gritty details of science are for the specialists, the trained scientists, but the big picture is for everyone. The subject of this chapter, the scientific method itself, is the frame of that big picture.
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If the Science Wilderness were viewed on a map, there would be no particular location for the fundamental forces you just read about in the last chapter. They underlie everything and can be thought of as the bedrock beneath every field, stream and mountain. The forces are everywhere, but often hidden and so, not obvious unless you’re looking for them. Energy is similar in that it can be found everywhere, but it’s not so hidden. Think of energy as the air; all the creatures breathe it, the plants sway in its movement, it brings weather and permeates everything in the landscape. Energy is perhaps the most powerful idea in physics. It’s the concept that all sciences use and it is central to the economy and the environment of the whole planet. The good news about energy is that you already understand a lot about it even if you fear you don’t.

Imagine a snow-day when the kids are free from school and they all trudge off into the white stuff with their sleds in tow. The destination is the nearest big hill, even if they must trespass to get to it! The ride downhill is so exhilarating, so free and such a break from the drudgery of school that they wish they could keep gliding forever. Not so. Eventually there is a bottom to the hill. This is where they laugh, extricate themselves from snowdrifts and try to find that lost mitten. They also slowly realize that in order to have more high-speed fun they have to trudge uphill back to the beginning. They have just realized a fundamental truth of the universe, the conservation of energy. In a nutshell, this can be summarized by saying that you can’t get something for nothing, but for science, this summary is too vague. We must define that something, energy. That is not an easy task because energy comes in so many different forms and identifying these forms is an acquired skill. So, how about acquiring some skill?

If you just said to yourself, “Why, yes, I’d love to acquire energy-identifying skills, but I just don’t know where to start. Darn,” well, then are you reading the right book! Let’s start with the energy of motion. When the sledders are moving down the hill, they have a type of energy called kinetic energy, named from the Greek word “kinetikos” meaning moving. The least kinetic energy an object can have is zero, when it’s stationary, of course. Kinetic energy was

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A movie theatre is often called a cinema, which derives from the same word, referring to moving pictures.
developed as a concept to somehow measure the “oomph” that a moving object possesses, the oomph that a stationary object lacks!\(^{25}\)

What the law of conservation of energy says is that if you want to set a stationary object in motion you must give it some energy or if you want to stop it or slow it down you must remove some energy from it. The more energy you give or take from an object will determine how much its speed changes. What’s fun about sledding is getting some of that oomph, and there are only two ways to get it. One way is to push a sled. Alas, this gets old very quickly, especially for the one pushing. (Well, the sled can be pulled, too, but that’s really the same thing and gets just as old just as quickly for the one pulling.) If you don’t live in Kansas, where all is virtually flat, you have another option and that is to slide down a hill.\(^{26}\) Now, instead of needing someone to pull or push, gravity “does the work” without any effort on your part, at least during the downhill run. Of course, to walk back up the hill, you have to do the work. Gravity merely “stores up” your effort to use later. It’s kind of like winding up the spring in a wind-up toy or charging up the battery on a mobile phone. Well, that’s not really accurate. It’s not kind of like these things, it’s exactly like these things. The children’s sledding neatly summarizes three of the four major kinds of energy: 1. Kinetic energy (KE); 2. Work (W) and; 3. Potential energy (PE).

Work is the actual pushing or pulling that is done to transfer energy from one form to the next. Work in physics is a precise term that’s not quite the same as in everyday conversation. To do work requires a force acting over a distance. If the force and the distance are at least partly in the same direction, the force (well, the object applying the force) gives energy to that object. If the force and the distance are at least partly in the opposite direction, the force takes energy from that object. When you throw a ball, you apply a force with your hand over a distance (the distance your arm moves) and give the ball energy; in particular, kinetic energy. When you catch a ball, you apply a stopping force over a (usually) shorter distance but since your force is opposite in direction to the ball’s movement, you take its energy away. We’ll later find out where that energy goes, and trust me, energy always goes somewhere! The law of energy conservation is 100% reliable on this. Energy doesn’t just appear and disappear.

Potential energy is energy that is stored up and available for later use. Potential energy is the kind of energy in a motionless sled at the top of a hill, a wound-up spring, a tank full of gasoline or a charged-up battery. Potential energy is the kind of energy that comes in the most forms and therefore can be the most confusing. Gravitational potential energy we’ve already seen with the sledders. (Or, like in the following, its name is usually shortened to just “gravitational energy.”) In a humble spring or rubber band, energy is stored in a slight distortion of the chemical bonds that hold the material together. This is sometimes called “elastic energy” and it occurs in any kind of solid material when it is bent, squished or twisted a little bit so that it snaps back to its original shape. (Anything will do this, at least a little bit, even rocks, glass and other “brittle” materials.) As long as the distortion of the material is not too great, the chemical bonds are only bent or stretched but not broken.

When chemical bonds are actually broken and perhaps formed or re-formed, we refer to that as chemical energy which is energy stored in the arrangement of atoms and molecules. “Burning” fuels simply rearranges the atoms! In an electric battery, the main storage mechanism is actually chemical as well, except that in the chemistry of batteries, the rearrangement of atoms and molecules is optimized to move electric charges around (usually electrons).

\(^{25}\) Another measure of oomph is momentum, which we’ll not consider here.

\(^{26}\) I live in southwest Florida, which is even flatter than Kansas and for sledders suffers the double-whammy of having no snow.
11. Atoms; A big idea in a small package

Charlene, a chemist, and her physicist friend Phil walk into a bar. Karaoke isn’t supposed to start for about an hour, so they begin discussing the nature of matter, that is, the stuff that everything is made of. There’s liquid stuff, solid stuff, gaseous stuff, green stuff, flammable stuff, hard stuff, soft stuff, etc. Now, chemists are experts as transforming stuff from one kind to another, so Charlene is explaining all sorts of tricks and gimmicks they use make Stuff C from Stuffs A and B. Fascinated, Phil pursues his inquiry, wondering how the chemist remembers all those different combinations.

“For instance,” says Phil, “you say that two parts hydrogen gas and one part oxygen gas combine to make two parts of liquid water.”

“Easy,” says Charlene, “I just remember the properties of hydrogen atoms and oxygen atoms and I can figure it out. Other atoms’ properties I might not remember, but I can look them up quickly enough.”

“Atoms?”

“Yes, atoms.”

“What’s an atom? I’ve never seen an atom.”

“I’m not surprised. You can’t see atoms because they’re too small,” chuckles Charlene.

Phil doesn’t laugh, but looks upset. “Well, if they’re so small that they can’t be seen, how do you know they’re there?”

“Because otherwise none of Chemistry makes any sense. All the evidence points toward the existence of atoms.”

“Do you believe in Leprechauns, too?” Now Phil is chuckling.

Based upon my extensive field research, I would conclude that the preceding is unlikely to be a common conversation in a bar today. But it was pretty much the conversation among chemists and physicists throughout much of the nineteenth century. The resolution of that debate is a story about the power of the Atomic Theory and about how science works. Instead of giving a historical account, though, I’m going to work backwards. Because the previous chapters dealt with heat and thermodynamics, I’ll start with the physics of atoms. By the late 19th century, physicists had mostly agreed with the chemists that the Atomic Theory just made more sense than any other idea out there. I’ll then introduce chemistry from within that atomic perspective.

Here’s an experiment that most of you can do. It requires no special equipment, but it does require a keen sense of observation and an inquisitive mind.

**Step One:** Place your hands together, palm to palm, and slide them back and forth past each other vigorously.

**Step Two:** What do you notice?

You probably don’t believe me that this is a profound experiment. Everyone knows what happens: Your hands warm up. Is this why you bought this book; a physicist pointing out the

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We’ll get to those “parts” and what they mean later.
obvious to you? If so, you’ve been had! (My publisher and I laugh on our way to the bank.) But, my publisher, though greedy, is not stupid. If you’ve been duped into buying this book, money is made in the short run, but you’re unlikely to purchase future titles; likewise the author. The experiment is simple and the outcome is familiar. The explanation, however, is far from obvious and cuts to the heart of what ordinary matter is made of and how we need to think about it in order to understand why it does the things it does.

One way of looking at this hand-warming experiment, a way that satisfies some people, is just to say, “Friction causes heat.” By doing that we just chalk up another fact among the millions of facts already on Mother Nature’s blackboard. But that is just stating a fact, not an explanation of anything. (And you want explanations, right? Right? Of course you do, because you’re an intelligent, curious person!) What about other ways to generate heat? What about the way heat moves when a hot object is put in contact with a cold one? Remember, science is all about finding universal principles that explain lots of facts. As it turns out, the Atomic Theory (that all ordinary matter is made up of atoms) is one of the greatest universal principles we have because it explains all sorts of stuff about heat, gases, chemistry, etc.

Oh, so you want the explanation? In a previous chapter, we learned all about the different forms of energy. Heat (thermal energy) was one of them. Kinetic energy (energy of motion) was another. Thermal energy is merely the kinetic energy of atoms in random motion; vibrating, flying and colliding into one another. Read that last sentence again and think very clearly about what it means. “Random” is essential. If I throw a baseball, I set all of its atoms in motion, so I give all of the atoms some extra kinetic energy. But, that extra energy is all associated with motion in one direction. The baseball doesn’t get hot just by throwing it. Thermal energy is the energy associated with atoms’ motions relative to each other. In order to heat up the baseball, I’d have to bump it against other objects (that include atoms of their own) to set its atoms vibrating about in random directions. Still, you wait, with bated breath, for the explanation of the hand-warming experiment. Here goes: Friction is, of course, the surfaces of two objects coming together and rubbing one another. If we consider that the surfaces are made up of atoms, then the contact between the two surfaces is really a set of millions upon millions of collisions among the atoms in those surfaces. These collisions will at least set the atoms vibrating. Because they are held in place by chemical bonds, the atoms are generally not going to move very far, but, like a hanging weight that’s bumped, it will start oscillating (a very fancy word for bouncing back-and-forth; use it to impress your friends and intimidate your enemies!). These new back-and-forth, random vibrations contain kinetic energy and this kinetic energy is what we now understand to be thermal energy, or more commonly, heat. It’s important that we not dwell on whether the particles involved are atoms or molecules. For the purposes of simple thermodynamics it makes no difference.

(excerpt, cont.…….)

It’s Alive! It’s Alive!
There is a reason that I’ve chosen to present biology, the science of life, last in our list of natural sciences. In our modern understanding called reductionism, science assumes that the same laws that govern chemistry and physics will also govern biology. Living organisms are made up of chemicals that undergo reactions and materials that exert forces, transfer energy and have electrical and optical properties, etc. Furthermore, life on Earth lives…on Earth, so to appreciate

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28 Which is far better than having baited breath. See what I said about the puns not getting better?
the history of life we must also understand the history and functioning of the planet itself, namely geology. So to fully understand living things, we can’t be ignorant of the sciences of non-living things. It doesn’t work the other way around; a physicist can be completely ignorant of biology and still be a very good physicist, albeit an ignorant one. A biologist has to master a much wider range of ideas to understand living things, which are arguably the most complex things in the universe. That’s a tough job. Let’s start with an appropriately tough question.

16. What is Life?

That doesn’t seem like a tough question, does it? We all know what life is, right? Well, think about it carefully. It’s not as easy as whether something is alive or dead. A dead something is something that was formerly living and has now ceased doing the proper things a living thing of that sort does; an air breathing animal stops breathing, a fish stops swimming for a very long time and begins to float or sink, a green plant withers and turns a crunchy brown, a bacterium stops taking in nutrients and stops excreting wastes. The essential question is what is the difference between living and non-living matter?

Is it movement? No, because most plants don’t move. Maybe it’s growth? Well, during some part of its life, maybe, but an organism can cease growing and still be alive. Reproduction? Consider the case of the mule which is a cross between a horse and a donkey. Mules are certainly alive but they are sterile and therefore can’t reproduce. How about metabolism, which is the overall process of taking in nutrients, processing them, doing stuff with the energy and matter in those nutrients (like growing a flower or writing a book) and then producing waste? Now we’re getting close, but consider the case of a virus. A virus is a microscopic organism smaller than a bacterium. They can be thought of as tiny capsules that contain some DNA or the very closely related RNA. They attach themselves to bacteria or other living cells and inject some DNA into the cell. The cell’s biochemical machinery then starts making copies of the DNA. That’s the cell’s job, and it has no way of telling whether the DNA is good or not. This is all at the chemical level and chemicals do what they and their environment have been set up to do. Additional molecular assembly processes build new virus capsules to hold the newly manufactured DNA. Eventually, all the cell’s resources have been exhausted and the cell dies, bursts and sends many new virus copies out into the world. These new virus copies repeat the process. This process will just keep repeating until all possible host cells are used up. It’s a ruthlessly efficient process and that’s why some of the worst and persistent diseases we know of are viral in origin, e.g. HIV/AIDS and the common cold. Here’s the curious thing, though. Between the time that a new virus capsule is released into the world outside of its host cell and the time it infects another cell the virus capsule does something very interesting: nothing. Absolutely nothing. It is inert. It doesn’t eat, breath, move on its own, poop, write poetry or in any way exchange matter or useful energy with its environment. It drifts along until it comes in contact with an appropriate target cell in the right environment and then its molecular machinery automatically goes into “attach and inject” mode.

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29 But geological history is profoundly affected by biology, which is responsible for many environmental factors, chief among them our oxygen-rich atmosphere.

30 But some do, like the Venus Fly Trap. I do not know of any plants that move their entire “bodies” around to relocate to a sunnier spot, etc. There are myths about “walking trees” but they are just that, myths.
Is a virus a living thing? That’s a very interesting question and one I urge you to ponder. It is a good question to think about if you’re having trouble sleeping.

Ultimately, I think the answer is unimportant. Whether something is “alive” or not is more about word definitions than actual scientific knowledge. We can study viruses and learn lots about them (we have) without ever knowing—or caring—whether they are alive or not. A very good bit of advice is to not worry about semantics and keep asking scientific questions like “How does this work?” or “What caused that?” A similar problem arises in biology when one tries to define the word species. Believe it or not, the central message in Darwin’s theory of evolution and origin of species is not very sensitive to how or if we define species! In planetary astronomy, Pluto was recently demoted from planet to “dwarf planet.” That alters nothing about Pluto except where we store information about it and how we refer to it; that, and perhaps what parties it gets invited to.

So, let’s stop worrying about whether or not we know what life is and get on to summarizing what it is we know about things that are living, or even sort-of-living.
17. Molecules to Man

In the early days of modern biology, in the 1700s and 1800s, there was no grand, organizing theme that guided scientific thinking about the living world. We had to wait for Darwin in 1859 for that. What “naturalists” at this time did was collect specimens and catalog them and fill what would become very large and dusty museums with these cataloged collections. Others looked through microscopes to find things that were hidden by the limitations of our eyes rather than the limits of our travels. These microscopists drew (no photography yet) and described what they saw and categorized the organisms according to their size, structure, origin or activity. There were also those who concentrated on how organisms interacted with members of their own species and other species in their habitat. So, the pile of information about living things of all sizes and from all corners of the globe was mounting rapidly.

Linnean classification; a tree without an explanation

Carl von Linné was a Swedish natural philosopher who lived in the 1700s. At this time before the label scientist was coined it was also fashionable to Latinize the names of great authors and historical figures. Thus, von Linné is more often referred to as Carolus Linnéus. He created a classification scheme, in Latin, for organizing all living creatures based upon appearance, structure and so forth. This brought organization to the chaos encountered by biologists (then still called naturalists or natural philosophers) when trying to relate the incredible discoveries being made all over the world by European explorers from various countries. It is his system that leads to the long, unpronounceable Latin names for such common animals as the pigeon (Columba livia). It may not seem like progress until you realize that this common bird can be referred to by a variety of names including rock dove, Taube, paloma, pombo, etc. Latin was chosen, as in medicine, because it is a dead language; not used in any current culture so it doesn’t change anymore.

This classification system ended up looking like a tree in most places when diagramed. The figure is an example for dog-like animals. The domestic dog is most similar to the wolf; indeed they can interbreed. Wolves and jackals share many characteristics, but dogs and jackals are more dissimilar. Coyotes (also called the American jackal, except in America!) are generally more similar to wolves than dogs. Based upon various
anatomical features, foxes and South American canids (like the South American maned wolf) are more distantly related to dogs and coyotes than they are to wolves, so the species are connected in the diagram as shown. When possible, all animal species were related this way. This was also done with plants. Because outward appearances and anatomical features were used there were very many cases where debates raged about what features should be more important when placing a species closer to one or another. Were habits, diet and coloring more important than bone structure, seed shape or habitat? There were no easy answers. Genetics would provide better comparisons, but it was not yet known in the 1700s-1800s. For all the struggles, though, the Linnean classification, also called taxonomy, gave all biology a common language to use and therefore enlightened and accelerated the study of all living things. Also, the trees looked similar to family trees for people and breeding diagrams used in keeping track of the pedigrees of champion horses or exceptional chickens, all tracing back to some common, ancient ancestor. This made some wonder about the history of the species; why were there so many similarities and what caused the differences?

(excerpt: content removed)

19. Darwin’s Great Idea

I, being a physicist and not a biologist, give in this chapter an account of the modern theory of evolution that would make a biologist cringe. It’s too brief, too simple, and skips all the subtle details and intriguing auxiliary subjects that biologists revel in. But they’re biologists and this is not written for them. It is written for non-scientific but intelligent individuals who want a quick, essential guide to understanding one of the most important scientific ideas in history.

The word itself (from dictionary.com)

**evolution**  *n.*

1. A gradual process in which something changes into a different and usually more complex or better form. See Synonyms at development.
2.  
   a. The process of developing.
   b. Gradual development.
3. **Biology**
   a. Change in the genetic composition of a population during successive generations, as a result of natural selection acting on the genetic variation among individuals, and resulting in the development of new species.
   b. The historical development of a related group of organisms; phylogeny.
4. A movement that is part of a set of ordered movements.

[Latin, from evolutus, past participle of evolvere, to unroll. See evolve.]

“Evolution” is a word that is generally used to mean change, usually a substantial albeit slow change in the essential characteristics of something. The etymology of the word is misleading and problematic for science, as “unrolling” or “unfolding” are not at all appropriate. Evolution does not express some predetermined future order of things that is somehow folded up and implicit in the present (or was implicit in the past). Evolution in science simply refers to the way or ways in which the variety of lifeforms on this planet has changed over the eons and is still
changing now. As we shall see, the seed of this change is randomness. Life stumbles and struggles to survive as its environment, i.e. the Earth, or a certain little bit of that Earth, changes. So, let’s start with those changes.

Change?
Yes, change. The Earth has changed dramatically over its history. This is now accepted universally among scientists, but it has not always been thought plausible, or even possible, throughout the history of human cultures.

At the dawn of modern science, Europe in the 1500s-1700s was almost entirely Judeo-Christian and accepted the Biblical account of creation; God creates the current life on Earth much as it is today, albeit with minor corrections due to the great Noachian31 flood. That’s understandable, as the tale was told to all since childhood and besides, anyone got a better idea? No one did. (Well, some did, but the ideas weren’t that widely known outside scholarly circles.)

With growing industrialism and the consequent need for lots and lots of metals, other minerals and coal, there were at this time many people digging many big holes to get the stuff they needed to, well, make more stuff! The emerging science of geology thus started to gather lots of new data about different kinds of rocks, the different layers they are found in, the ordering of those layers, etc. The picture emerging from all this was that the Earth’s surface seemed to have been covered, and recovered, and recovered…by various types of rocks from very different sources; volcanoes, sediments deposited by rivers and oceans, etc. It was clear that at some time in the past, your backyard in, say, Germany did not look anything like it does now. Now, that past time must have been way back because nobody you know, or nothing you have ever read by anybody has mentioned a volcano in Munich. Surely it would have made the history books!

Alongside this emerging view of a dynamic and perhaps very ancient Earth were the increasing number of discoveries of strange animal remains buried in many of these exciting new rocks. (Recall that the rocks were exciting to geologists; as a general rule they like rocks; go figure.) Now, such finds had been made since antiquity; the Greek natural philosopher Thales found seashells atop a mountain, from which he readily concluded that all is made of water. OK, so that theory didn’t hold up very well, but another explanation might be that what is now a mountain was once part of the bottom of an ocean. Remains of palm trees and other warm weather plant varieties were found…in frozen Scandinavia and cold, northern Canada. The strange plant and animal remains provided further support to the idea that the Earth has a very long and dynamic history.

The fossils
The aforementioned remains were not only deemed strange by their locations. The “bones” differed from bones buried in the backyard by the family dog in that they weren’t really bones. Sure, they looked like bones, even complete skeletons of bones. But they were made of…rock, not bone. Apparent twigs and tree stumps were also made of rock; now said to be “petrified”,

31 “Noachian” means related to Noah, the builder and captain of the Ark in the Bible’s Genesis, chapters 5 through 9 especially. It’s pronounced no-uh-key-un and you can use it to show off, just like I did. As I don’t want to exclude anybody, I’ll summarize: God asked Noah to build an ark (large barge-like ship) to carry his family and breeding pairs of all animals (ALL!!!) while the Earth was flooded. (God was punishing evil people and, apparently, evil animals and plants as well.) Once the flood waters receded, Noah and his family repopulated the Earth and the animals also went forth and repopulated. It should be obvious to any reasonable reader that the story is physically impossible, but I’ll leave that research up to you. What’s important here is that many people then and now believe it to be literally true.
literally made into rock. They had obviously undergone some sort of chemical transformation that doesn’t take place overnight, or “over centuries” for that matter, as people in England could dig up centuries-old Roman settlement remains and not find such transformations in wood or bone. Such transformed-into-stone remains are called “fossils.”

But wait, there’s more! Not only the locations and composition of the fossils were noteworthy. In fact, the most amazing thing was that some of the bones and plants were unlike anything known to currently live. Anywhere. Particularly intriguing were teeth, skulls, and even whole skeletons from what appeared to be very abnormally large lizards. Big, terrible teeth and claws led to the name given the creatures that left us these fossils, dinosaurs (terrible lizards, from the Latin).

So, the fossils needed to be explained, and the challenge to explain them was an old one. Since ancient times people found some curious bone-rocks in curious places. Francis Haber refers to this as the “fossil enigma.” The fossils begged for an explanation because they were just so strange. Some historians have suggested that many of the ancient myths about large dragons, Cyclops, etc. may have come out of a folk attempt at explaining the reasons for these fossils. Scholars had from time to time offered more thoughtful, if less entertaining, explanations.

Aristotle, the Greek philosopher working c. 300 BC, thought that fossils arose spontaneously out of some organizing principle in matter, some “plastic” force.32 They were never really living things, but only incomplete formations in some sort of primordial mud. Maybe he thought that if the mud were in a better location they would have emerged as living organisms. This notion seems odd to us now, but until the dawn of the scientific revolution, people widely believed that living matter arose spontaneously out of non-living matter. This theory was promoted by Aristotle and his followers and is called spontaneous generation. For example, fly larvae (maggots) spontaneously form on decaying heaps of food and garbage. Later experiments showed that the flies don’t spontaneously emerge but are actually the result of adult flies laying eggs on the decaying matter.

Leonardo da Vinci also had something to say about fossils and what he said was perfectly consistent with our modern understanding.33 He realized that the fossil organisms had to have been deposited slowly over vast stretches of time and that they were indeed the remnants of ancient life, not some mystical forms growing within the rock. They didn’t appear in every kind of rock and appeared amid sand and broken shells just like a modern beach or shallow seabed. He also noticed that the same fossil layers could be found throughout a region and matched at the same height across river valleys, which he realized were cut by erosion through a previously solid block of land. In short, Leonardo was way ahead of his time in realizing the meaning of fossils in understanding the true history of the Earth. Before you jump to conclusions and claim he had some sort of eerie link to modern thought, I must also point out that his grand theory of the Earth’s dynamics, based upon the powers of water (which for him was one of the four elements; earth, air, fire and water) and an analogy between the Earth and a living body, was completely wrong. What’s important is that his observations of fossils and the immediate conclusions drawn from them were scientific and logical in every modern sense. It would take

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32 Not plastic as in the types of chemicals we make many items from, but plastic in the sense of being able to be formed and shaped. This why the materials we call “plastics” are called plastic; they are easily shaped and formed by various heating, cooling and chemical processes.

33 For a very learned account of Leonardo’s contribution I recommend the first chapter of the book Leonardo’s Mountain of Clams and the Diet of Worms by Stephen Jay Gould. Gould’s writings are a testament to the beauty and logic of many aspects of evolution. A scientist with an incredible background in the humanities, he weaved science education with forays into history, arts and literature.
four centuries for the rest of the world to catch up to his ideas, primarily because he published so little of his work. What he wrote was tied up in cryptic notebooks. The one which contained his observations of fossils was not known until the late 1900s.

Well, I could go on and on about old ideas and their relative merits and shortcomings, but the bottom line is that **everyone knew about fossils and the fossils needed to be explained.** From our modern viewpoint we can say the following. Evident in the geological record is a progression of fossils, from the very simple in the Pre-Cambrian era, from 3000 up to 600 million years (MY) ago, more complex in the Cambrian era (600-250 MY), etc. on up to the more recent Mesozoic (250-65MY) and Cenozoic (65MY-present) eras. The names of the eras are not essential and are not entirely logical, but sound very impressive when spoken at cocktail parties; scientist cocktail parties, that is. Note that the dates given above were only accurately determined long after Darwin walked the Earth. Darwin knew the Earth was old, but estimates during his time tended to be in the tens or hundreds of million years. New estimates of 4-5 billion (4000-5000 million) years give his theory much more time, and therefore much more plausibility, than it had in his day.

So, lifeforms changed in the past. **That’s key idea #1.** Whence the change? Evolution means that change occurred, but how? Before Charles Darwin formed his theory of evolution by natural selection, a number of other thinkers tried to explain the changes in the Earth’s living history. Erasmus Darwin, the grandfather of Charles, proposed a very vague notion of all life arising from perhaps a single initial living organism and thence differentiating and splitting into the many forms we have today. Jean-Baptiste Lamarck, working after Erasmus but before Charles Darwin, put forth the notion that individuals can acquire traits during their lifetimes and then pass those traits on to their offspring. Lamarck’s chief error was in supposing that an animal’s will was important in the changes it underwent. E.g. a giraffe, trying to reach ever-higher leaves in trees, strains its neck, which lengthens. This lengthened neck is then passed on as a trait to the giraffe’s offspring. This is problematic for plants, which have no will. Furthermore, the whole notion of inheriting acquired traits is contrary to modern genetics. But Lamarck didn’t know about modern genetics, so who could blame him? He does get credit for at least trying to come up with a scientific explanation.

Others, such as Buffon, and Charles Darwin’s grandfather, Erasmus Darwin, also had their theories. For our purposes here, let’s stick to learning about the current accepted theory rather than lots of discredited ones. I only mention them for two reasons: (1) It is important to remember that other theories were in competition with Darwin’s and only the best scientific theory can survive. (2) Darwin was not alone in his wondering about some sort of evolution as a means to explain the fossils and life’s diversity. Others surely would have thought of his theory had he not published his work. In fact, Alfred Russell Wallace was pretty much ready at the same time with the same ideas; Darwin beat him to press, but just barely.

**A population is a key idea #2.** A species is identified by the common traits among the members of that species.\(^{34}\) I will define a species as organisms that can interbreed and produce viable offspring (offspring that can themselves reproduce; fertile). Consider a population of red rose

\(^{34}\) I will avoid here the very troublesome issue of the *exact* definition of a species. Biologists cannot distill it down to a single phrase, due mainly to the variety of organisms that are known to exist. This is a BIG issue among biologists, but it’s a very technical one. Some critics of evolution will complain about how biologists can’t define a species so any talk about “species changing” is nonsense. The critics are missing the point. No matter how you define the word, it is clear that now and in the past species have changed.
plants that are related to each other (are common genetically and can interchange pollen, etc.) A single individual rose plant may have a gene for, say, yellow flowers. But this may be a genetic fluke; a mutation that may have occurred in the seed that grew into that plant. That gene, however, is not an important part of the population unless it gets spread around to the extent that many of the roses in the population have yellow flowers. Once that yellow gene gets around, it is part of the population’s pool of traits. This is crucial because the success or failure of the population may rely on these traits. (Imagine a herd of hungry deer that eat red flowers but leave yellow ones alone! You’ll read more of this under “competition” below.) Biologists worry about populations because they are what survive generation after generation, not individuals. A species may have several distinct populations, most commonly separated geographically. Human “races” are a good example. Before quick and easy intercontinental travel each population had distinct genetic features that yielded distinct outward physical traits. Yet, despite these differences, all races can and do interbreed with others. We are one species.  

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**A summary of key points**

So, a summary of the major ideas in the modern theory of evolution by natural selection:

1. Change has occurred.
2. Populations of animals are the real units to watch and think about, not individuals.
3. Traits are inherited from parents.
4. There is variation among individuals in a population.
5. Animals in a population compete with each other for survival. Those that survive long enough to breed pass on some of their traits. Some of these traits may have been the reasons for their survival! Thus, survival traits self-perpetuate in a population.
6. The Earth is about 4.5 billion years old. Life has been here for about 3 billion years. There has been lots of time for change to occur. 

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35 The traits of these various races may be in part accidents of history and geography, but in some cases are directly related to survival. For example, skin color. Dark skin is a trait common to those races that are indigenous to sunny regions near the equator. It helps protect these people from skin damage due to the sun’s ultraviolet rays but also, it turns out, that too much sunlight will decrease the amount of folate, an important B vitamin, in our bodies. Light-skinned people tend to be less healthy in the tropics, so even if there were originally a mixture of light- and dark-skinned people in the prehistoric tropics, the dark-skinned folks would eventually have a better survival and reproduction rate. So what about the temperate and arctic regions where light-skinned people dominate? Why would they be light-skinned? Wouldn’t they also benefit from the sun protection, too? Yes, they would. But, it turns out that sunlight entering our skin produces vitamin D by altering some chemistry. Even with their dark skin, the tropical sun crowd gets enough vitamin D. But, if a prehistoric dark-skinned person moved to an extreme northern or extreme southern environment, they would likely develop a vitamin D deficiency which can lead to the disease called rickets and, possibly, death. So, there is a balancing act here that favors light skin in temperate regions and dark skin in the tropics. This is not 100% accurate, though, as diet can also make up for vitamin D deficiencies. Also keep in mind that I’m talking about prehistory here: modern diet, clothing, shelter, sunscreen and vitamin supplements can make up for all the effects of sunshine. Pause for a moment here and think about skin color as purely an artifact of vitamin nutrition and sunlight. It’s moments like this that show us what societies can learn from science. If we want to think about race, we’d better have our facts straight. Evolution helps us gain some much-needed perspective.
Part III. Natural Science in Context

20. If it Quacks Like a Quack; Pseudoscience and Junk Science

Our modern civilization has come to depend on science. We know that it has made possible all the technological innovations that ease our lives and increase our standards of living; electricity, computers and information at our fingertips, entertainment, clean drinking water, air conditioning, safe foods, and medicines without which many reading this book would not be alive, including yours truly. Science has also made possible some of our worst problems; chemical pollution, the capability to make widespread environmental changes which destroy wildlife habitats and change the climate, and truly horrible weapons. Both faces of science are used by proponents, practitioners and purveyors of pseudoscience to sell us something that looks like science but isn’t. I am firmly convinced that this is a bad thing and by the end of this chapter I hope that you’ll agree. If true science is represented by our Science Wilderness, then pseudoscience would be a pale imitation; potted plastic palm trees and stuffed animals with prerecorded jungle sounds emanating from poorly hidden speakers.

This chapter is all about defining pseudoscience and showing you how you can spot it, avoid it, and educate others to do the same. Why do I hate pseudoscience so much? It is wrong. It flies in the face of what is really known about the way the universe works and the way we can learn new things about how it works, the scientific method. Why is that bad? Let me count the ways.

1 Because it may contradict known laws of nature it is exceedingly unlikely to work as advertised. If it does work the explanation is incorrect. The results can be as minor as a bit of confusion or as major as death.
2 It wastes time and money on products, policies or practices that ultimately prove ineffective. This may be followed by another attempt at a solution of what has likely grown into a larger problem if it is not already too late.
3 It is confusing because it mixes incorrect information with correct information, leaving the victim in a fog about what is true, what is not and when pseudoscience fails it generally dissuades the victim from trusting anything sounding even remotely “scientific.” Simply put, when pseudoscience poses as real science it ruins the reputation of the real thing.
4 It asks the victim to place his or her trust in a personality or disembodied authority, like an ancient text or lost culture, instead of reason and solid physical evidence. This, the “argument by authority,” is one of the classical examples of bad logic. Accepting “facts” from an authority just because of its source is one of the ways Hitler and similar despots came to power. This is a habit of thinking we ought to discourage rather than encourage.
5 It relies on primitive modes of thinking and emotional decision making. These are the opposite of not just science but all careful, reasoned thinking that we need to rely on in politics, dealing with our environment, raising and educating our children and our own personal decisions.
6 Pseudoscience encourages conspiracy theories. This is almost inevitable when pseudoscience promotes facts and/or theories that are in direct opposition to established knowledge in mainstream science. The question that immediately arises is why science
doesn’t accept these ideas. Because the reasons may be very technical and may require expertise, or at the very least long explanations, to understand, science then looks as though it’s evading the question and hiding something. Ah…a conspiracy!

Pseudoscientific explanations and descriptions are too easy, too lazy, in comparison to most real science. That makes pseudoscience more accessible to the public, which is an important reason for its popularity. It also breeds a mentality that the complications and rigor of traditional science are unnecessary and even a waste of time. This has the side effect of making the public impatient for easy answers when there might not be any.

Categories of Pseudoscience
Pseudoscience takes many forms and there are numerous examples. You are probably familiar with many. Here is a partial list of some of the most popular.

- Parapsychology, which includes
  - telepathy (sending and receiving thoughts with the minds only)
  - telekinesis (moving objects with the mind)
  - ESP (extrasensory perception) a blanket term that encompasses any form of sensing outside the normal five senses; foretelling the future, remote viewing and telepathy
- Paranormal, which includes ghosts and spirit possessions, communication with the dead, hauntings and the like
- Fantastic and mysterious animals, like Bigfoot, the Yeti, the Loch Ness Monster, New Jersey Devil, El Chupacabra, etc.; this is called cryptozoology
- Quack Medicine, which includes
  - Homeopathy, which is the use of very dilute solutions of ingredients in pure water touted as powerful medicines
  - Some aspects of Chiropractic medicine, particularly those that blame various diseases such as allergies, cardiovascular disease, cancer, etc. on spinal alignment problems
  - Many traditional medicinal practices and substances from ancient cultures; herbal remedies, home remedies and rituals. Note that some substances are ineffective placebos. Others can be very powerful substances that can do real good and real harm.
  - “Energy” devices that treat the body with various electronic or radiative emanations
  - Special materials, such as certain metals, crystals and magnetic alloys, used in jewelry or other externally worn forms that are claimed to cure or treat a wide variety of ailments
- Astrology, using the sun/planet locations to predict things about your personality, romantic prospects, talents and events in your future
- Numerology, using numerical coincidences to characterize events and predict the future. This takes many forms, from ancient Hebrew Kabbalah and Greek Pythagoreans to recent obsessions like the Bible Code.
- Creationism, which puts forth the Biblical account of creation as actual natural history; to do so, creationists must reject almost all of modern science and claim that the Earth is young and that most of what we know about the history of the Earth and our universe is simply wrong.
- Intelligent Design, which is the replacement for now-waning Creationism among the large portion of the U.S. population that still hates evolution; The claim is basically that the evolution of life could not have been an entirely natural process but must have been helped along the way by some intelligence driving at least some part of the process.
- Claims of ancient civilizations possessing advanced technology or powers. Did the ancient Egyptians and Druids use levitation to lift the large stones they used to build the pyramids and Stonehenge, respectively? Maybe they had psychic powers or supernatural help?
- Or...maybe the ancient humans had help from extraterrestrials. It is a very popular idea that combines fascination with ancient humans and the wonder that there may be other intelligent life “out there.” All UFO/extraterrestrial topics are pseudoscience if they claim actual contact with aliens. So far, there is no evidence.
- While mostly categorized as religious, spiritual or philosophic in nature, some “New Age” beliefs cross into pseudoscience when claims are made about the structure and functioning of the physical world, most notably the human body in various stages of health and disease. A good example is Therapeutic Touch.

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Imagine two bordering countries at the brink of war. One, Sciland, accuses the other of interference in its business, encroachments on its farms and industrial operations, and unfairly restricting commerce in its rapidly developing economy. The other, Religia, views Sciland as too aggressive and even expansionist. Even if Sciland’s armies don’t cross the border, the pollution from its industries wafts or flows over and threatens the stable society of Religia that has existed for thousands of years. The Science Wilderness is located in a vast region between Sciland and Religia. Because of its remoteness and ruggedness, the Wilderness area has not been surveyed accurately so there are large disagreements between the two countries as to where the border lies. Both countries exploit the natural resources of the Wilderness to such an extent that they depend on it for their vitality and maybe even their very survival.

How might the conflict be resolved? There are nearly infinite possibilities, but let’s focus on three main types of resolution; Victory, Wall and Compromise. (I’ll capitalize these words when I refer to the models.) Victory is just that. Let them fight it out and one side wins, the opponent gets crushed. If outright warfare is abhorrent to both sides, however, but they still find their differences irreconcilable, they may choose to build a wall between the countries, posting sentries and enacting laws that greatly discourage any interaction between the two countries. If there are those on either or both sides that see something of value across the border, they may work to make peace by means of compromising. Compromise will always mean that you must have some mixture of accepting the opponent’s positions on some things and giving up some of your own positions. In that case, neither side will ever be the same as it once was, which may be

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36 For those who are being hopelessly literal, Sciland is like science and Religia represents religion. For those who spotted that clever (?) bit of naming but think I am being too simplistic in my summary of the border dispute, all I have to say is you’re right. It’s an analogy and all analogies are imperfect. An analogy is like a…
a good thing. Then again, it may mean the destruction of both cultures and the forming of a new one.

The Nature of the Conflict
Why are they fighting? Why do science and religion (S&R) seem to clash? I think there are two main types of clashes that make the headlines; those dealing with ethical implications of science and technology and those that deal with more fundamental beliefs about the nature of reality. It is the latter I wish to discuss here, so let’s dispense with the former right away.

There is no shortage of opportunities for debating ethics when considering the natural sciences. Most of these take the form of moral or ethical questions that arise when discussing the use of new science or technology. We’ve invented X, should we use it in situation Y? Examples here include life support for critically ill patients, nuclear weapons, birth control drugs and electronic surveillance. The other obvious class of ethical issues arises when discussing the process of scientific research: experimental ethics when dealing with human or animal subjects, intellectual honesty among scientists, peer review and so on. I will mostly avoid these in this chapter, as I am trying to get at something more fundamental than the application of technology.

How about a simple example to start? Let’s say a particular religion, Greek mythology. Taken literally, the myths state that the Greek gods, the Olympians, make their homes at the summit of Mt. Olympus in Greece. This is a claim that can be directly tested by simply climbing Mt. Olympus and having a look yourself. It’s not a particularly difficult climb even with primitive climbing gear, essentially feet and hands. You will find no gods there. Indeed you’ll find no palace. Here is a clear conflict between a physical claim made by a religion and direct physical evidence. If the claim to a godly palace atop Mt. Olympus is essential to this religion, then it crumbles in the face of physical evidence. To resolve the conflict in the Victory model you could either eliminate the religion and its ties to culture, politics and economics or somehow suppress the physical evidence.

Eliminating the religion is not easy. There are lots of people depending on the religion for their livelihoods and their social structure. Priests and temple workers might be instantly out of work. How would people view their world, their morality? What would people do on religious festival days? How do politicians unite the people? If, for social reasons, the religion may be on the verge of collapsing anyway, this could be the final reason people might need to reject it completely.

Defending the religion may be easier. If the leading class had the opportunity they could have the mountain-climbing messenger killed, imprisoned or branded as a lunatic. There could be further assurance against future mountain climbers by outlawing the practice or, if that’s not practical, starting a legend that monsters lurking in the foothills or even the gods themselves will destroy any summit seekers. Even if this worked it would be a temporary solution at best. Eventually someone will climb and tell.

In philosophy and debate there is a tactic called the Straw Man argument. In using it, a person will set up a flimsy example for discussion that is designed to fall easily to their arguments. The analogy is a fighter showing his strength by setting up a straw man and then

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37 Actually, there is a lot of insight in recognizing that what makes the headlines is a big part of the problem. In the popular media, which can be described as entertainment biased, only the juicy stories get told. So, we only hear about science and religion as an issue when it’s a fight. Most of the time, as we’ll see, scientific knowledge does not elicit any sort of religious response because it simply doesn’t matter to religious issues.

38 Mythology is a term usually reserved for other peoples’ religions; never your own!
knocking it down; not impressive. Such is my example of Greek mythology. I represented the religion as claiming that there is an actual palace atop Mt. Olympus right now. Did the ancient Greeks really believe such a thing? Probably not. Most Greeks regarded their myths as allegorical stories that have some moral or existential truth but may not be literally true. Even when they did think of them as literally true in part, many regarded the age of gods and monsters as something in the past and that the gods did not act so publicly “nowadays.”

So, when a zealous mountain climber returned to Athens and confronted the priests and people with his revelation he would likely have been met by some with wry smiles and been told, “We don’t believe that there is literally a palace atop Mt. Olympus!” Still others might respond to the priests, “We don’t believe that? I thought we did!” Religious ideas vary greatly among people that claim to be under the same label. Some are more literal with sacred documents or traditions while others take a more interpretive approach. This is where it gets very tricky because once you start interpreting different interpretations start arising.

The moral of this little story is that when facing a situation where there is an apparent conflict between science and religion I urge you to stop and be sure what is being claimed on each side of the conflict before diving into the debate yourself. Many controversies are more a result of misunderstanding than real conflict, with zealots on either side knocking down straw men rather than talking to each other.
Newtonian Physics; the Clockwork Universe
We’ve already met Newton and his laws of gravitation and motion. The punch line of all that Newtonian physics is that the physical world around us, the motions of everyday objects like beach balls and rings around Saturn, are the results of these laws and the peculiar circumstances of the objects. Put another way, if you know the physical details of some objects (shape, mass, etc.), where they are and how their moving then you can, in principle, predict where they’re going to be some time later or where they were sometime in the past. The universe proceeds according to regular laws that it cannot deviate from. In practice it is difficult to predict or retrodict accurately, mostly for mathematical reasons, but it is, in principle, possible. This universe has been described as a “clockwork universe” in analogy with a mechanical clock, the gears of which constrain it to move in a particular way. When these laws became widely familiar they began a vigorous discussion of their implications about God and how He (It, She?) related to the universe.

In the Victory model, the laws would either support the existence of God or provide evidence against His existence. Both have actually been part of Newtonian physics. Newton was a devoutly religious man. He was obsessed with many ideas in Christianity and studied theology, writing more on that subject than science! When he initially applied his laws to the study of the solar system he found that his ideas about gravity and motion explained the general features of the orbits nicely. As he got deeper into considering the effects that the planets would have on each other, though, he became convinced that the laws predicted an unstable solar system, one that would have fallen apart into chaos within human recorded history. He therefore concluded that some influence was actively working to correct the orbits and keep them stable. To him the influence was obvious; his familiar God.

On the contrary, Newtonian physics is usually discussed as being on the opposite side in the Victory model. Shortly after Newton’s death, other mathematicians and physicists took up his laws and developed them further. With increasing mathematical sophistication they found that Newton was premature in his assessment of the planets’ orbits and the instability of the solar system. Newton oversimplified the situation and once these more advanced techniques were brought to bear on the issue it was found that the solar system would be stable under Newton’s laws. Armed with this knowledge, one of those scientists, Pierre Laplace, said of God, “I have no need for that hypothesis.” This is a famous quote that is often taken out of context. Laplace was referring specifically to Newton’s assertion that some extra agent was needed for the stability of the solar system. But Laplace and others, particularly French thinkers of the time, were starting to see science as a replacement for the primitive mythology of our past. On this side of the Victory model, religion is cast aside as being unnecessary because science gives us all we need to understand the world. This is the beginning of our modern S&R debates.

The fact that neither side has yet convinced everyone that a victory has been won indicates that the issue might not be so simple. Indeed, you’ll see here that the various models of interaction are a matter of personal or societal preference. You’ll see that in yourself as you think

39 I’ll use the traditional Judeo-Christian capitalized “God” when I’m referring to that concept of a god. Likewise, I’ll use the traditional He, His, etc. pronouns. I’ll use the lowercase when I’m referring to a more general concept of a deity.
40 Another caution here about the nature of scientific ideas: Even the original creator of the idea may not be the best expert to consult. Scientific knowledge expands and improves over time.
about these issues and learn about more issues throughout your lifetime. Expect this to be an ongoing process!

   Where is the Wall in this debate? There are, I think, two walls that can be built here. The simplest wall we have already seen in our early discussion of the methodological naturalism, also called the empiricism, of modern science. Science, in this view, can only comment on things in the physical world. If Newton’s laws describe the solar system well, so be it; that has nothing whatsoever to do with religion or music or politics or anything else supernatural or ideological that humans argue about. This is THE WALL; a wall that clearly defines the limits of all science and not just the application of science to a particular part of the world.

   The second wall is more immediate and pragmatic than the first. It is also hastily built and may not be as impenetrable. Some who saw the power of Newton’s laws were impressed with the technical accomplishment but thought that the true importance of their God was not really threatened by it. To these people, the dirty details of planets, rocks, orbits and projectiles were trivial. The true wonder of the universe was life and aside from concluding that sheep couldn’t fly, Newton’s laws were almost useless for understanding life. So, one way to deal with Newton’s clockwork universe was to put up a wall between the clockwork and living matter. This worked for a while until biologists and chemists started taking apart life, as we’ll see below in our discussion of evolution.

   Under Compromise, one can allow God to have some hand in the physical universe, but a limited one. Increasingly popular at about this time and place in history, the 1700s in Europe, was a religious point of view called Deism (pronounced “dee-ism”). Simply put, Deists believe that God created the natural world and set it up with physical laws via which it essentially kept going of its own accord. The classical analogy is a clockmaker who builds the clock, winds it up and walks away, leaving the clock to run on its own. Now, our universe would have to have a pretty big spring to have run for 14 billion years, but this is God we’re talking about. The traditional view of God is that He has no limits and can create anything He desires. In this analogy, God does not intervene in the day-to-day or even eon-to-eon operations of the physical world. The Deist idea effectively eliminates any possible conflict between science and religion because it logically excludes it. Again, many thinkers of the day were Deists, including some of America’s Founding Fathers. Einstein was much of the same mind. Bear this in mind when reading some quotes from them. When someone says “God” do not assume that his or her definition is the same as yours or someone else’s. For some religious people the Deist compromise is far too harsh. It effectively destroys the very concept of a personal, interactive God that is, for them, the essence of their religious beliefs.

   Evolution
   When Darwin published his theory in 1859 he knew there was going to be trouble. The S&R debates that raged on Newtonian physics had largely quieted by then, with the various camps formed, the wagons circled, etc. It was fairly easy to keep God and the supernatural out of the solar system, but now a theory was proposed that explained how life changes over time, how species originate. Especially important were ideas about the origin of one of those species, homo sapiens. In Darwin’s view, humans were evolved just as surely as wombats and wildflowers. 

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41 Could God build a spring so large that even He couldn’t wind it up? This is a variation on a classical logic puzzle.
42 Darwin skirted around human evolution in The Origin of Species (1859) but hit it head-on in his 1871 book, The Descent of Man, and Selection in Relation to Sex.
This suggested strongly that there is nothing special about humans, which was always a tenet in most of the world’s religions.

Furthermore, evolution was part of a growing movement in science to explain the origins of the world as we know it in terms of physical forces, of cause and effect. About this same time geologists were coming to the inescapable conclusion that the Earth was old, amazingly old, and its features developed over millions of years (they had not yet arrived at our larger modern estimate of billions). The traditional Biblical account of Genesis has the Earth forming in just six days in the hands of the Creator. Geology and evolution stated flatly that the Genesis story could not be literally true.

For Victory, either science or religion has to rule the day. For science Victory advocates that meant these new theories were the final nails in the coffin of those old religious myths; surely no sensible person would believe that stuff anymore! One is then forced to at least alter considerably one’s notions of God or abandon faith altogether.

For those wishing to preserve traditional, literal, Judeo-Christian ideas about the origins of world and man this meant that the new theories had to be wrong. This was the beginning of what is called Creationism, a belief that the Genesis account is essentially a factual account of what really happened. There is a wide range of modern Creationist views, ranging from the strict literalists to those who take Genesis more metaphorically. The strictest Creationists are referred to as the Young Earth Creationists. They understand that for evolution to be a viable theory the Earth must be very old. So, they claim that the Earth is about 6000 years old and that all evidence and argument to the contrary is incorrect. Either the science is wrong or the evidence is misleading. The former possibility is insulting to scientists, generations of them, that have worked very hard in fields and labs and have concluded that the evidence clearly shows an ancient Earth. As insulted as the scientists might be they must allow that they could be wrong. After all, falsification has to be possible if this is true science. Creationists are quick to point this out. The latter, that the evidence does indicate an ancient Earth but that the evidence is misleading, is curious because it can mean that God planted the evidence so consistently that it forces us to come to an ancient Earth conclusion. One is then put in a position of trying to guess why God would do such a thing. One popular idea is that the evidence was put there to test our faith; to see if, in the face of evidence and reason, we will still believe the literal words of the Bible. Some religious people are comfortable with this notion of a God and some are not.

The Wall approaches also work to eliminate friction between evolution and religion. Again, the most powerful wall is the natural/supernatural wall that gives the entire physical universe to science and leaves only the supernatural to religion. A trouble with this approach for many religious thinkers is that it raises serious questions about Scripture. If large portions of Scripture are to be thrown out, or at least taken metaphorically, what portions can be still taken literally? This is a huge part of modern theology in all branches of religion, not just Christianity. There are countless books filled with debates about how to interpret Scripture and the histories of the various books that are used in the various religions. There are no easy answers here.

The weaker wall I spoke of earlier is one that grants to science all this evolution and geology but puts a wall, OK a fence, around humans and says that we are effectively different from the rest of the natural world. Sure, we may have had ape-like ancestors but something special happened to us along the way, a special nudge or intervention by God that made us sentient, that gave us souls. I’ll explore this a bit more below in the discussion of the Ghost in the Machine.
Compromise has taken place in many religions and religious individuals in the face of evolution. If one accepts the physical truth of geology and biological evolution then the creation myths are just that, myths; stories written by primitive societies who tried to understand the origins of the natural world without the benefit of several hundred years of modern science. Effectively, then, what this means for Scripture is that all the literal stuff about actual history, etc. is completely unimportant. What are truly important are man’s soul, morality, and salvation. Or, how we behave now and how this affects our afterlife (or subsequent lives, for religions that include the idea of reincarnation) is the central issue. This view of religion as primarily a set of ideas about morality and personal transformation rather than actual physical facts is for some faiths a rather new development (e.g. Christianity) but as old as the religion itself in some (e.g. Buddhism).

I would seem so far that all the Compromise models have religion doing all the compromising. “Not so fast,” say some religious thinkers. What if science is wrong, not wrong in the sense of screwing up with radioisotope dating and identifying fossils, but wrong in its very method? What if disallowing the supernatural in forming theories puts science off on the wrong track to begin with? Sure, much of science has been very successful by eliminating the supernatural, but these thinkers would argue that science is therefore necessarily incomplete and handicapped when it comes to some of its subject matter, usually evolution and cosmology. Intelligent Design (ID) is a prominent example of an idea that seeks to explain the natural world in terms of a mixture of limited scientific reductionism and supernatural intervention. But ID is just one such example of a much larger set of ideas that come under the umbrella of “theistic science.” Some prominent figures in this vein are Pierre Teilhard de Chardin, Robert Wright, Alvin Plantinga and Michael Polyani. They all argue that our construction of knowledge should include not just physical experiments and standard theories, but personal (including religious) experience. This I consider to be a very radical compromise on the part of science (OK, I’m biased!). It raises the question of when and where it is appropriate to allow for the intervention of the supernatural or personal experience. Would you be satisfied if your physician diagnosed one of your ailments as being supernatural in origin? Most would not, which is why these ideas operate at the level of the grand theories of science, not the practical every day theories that describe chemical reactions and photocopiers.43

The Ghost in the Machinery of Life
Very much related to the ideas of theistic science mentioned above, there is an idea that complex systems, for example life, are overwhelmingly intricate and fine-tuned when seen as a whole. It is very easy to imagine an invisible hand of a vital force or some intelligent designer that “explains it.” Words like baffling or incredible may be used when describing a biological structure or the set of coincidences in our universe’s history. Yet, when looked at in fine detail, scientists understand the individual subsystems, like genetics, cells, natural selection, gravity and interatomic forces. Every part makes sense, yet the whole is somehow mind-bogglingly complex. Surely, say some, the whole must be greater than the sum of its parts.

Science is always incomplete, as you know, because there are things we have not learned yet. What if there are things about the physical universe that we can never know, however long we try? In most of the thinkers who see reductionist science as somehow incomplete, in

43 I still have my suspicions about magic in those copiers, though!
principle, there is what I like to call an appeal to a Ghost in the Machine. That is, somewhere amid the chemicals and cells and dark matter of the universe there are hidden but influential supernatural agents at work. These do not have to be demons or angels, but some liken them to “organizing principles” or tendencies that are not described by our mechanical theories. In Intelligent Design, the organizing principle is some intelligent designer. Some other ideas postulate some organizational or progressive trend which leads to life and intelligence.

The problem with this approach has always been that as scientific knowledge advances, the need for ghosts diminishes. There is an old term for this notion, at least when God is used as an explanation for the gaps in our understanding; the “god of the gaps.” The wall, or fence, keeps moving too keep up with scientific progress, relegating God to an ever-decreasing domain. Most religious thinkers in the field of S&R interactions do not like to diminish or cheapen the concept of God like this, but prefer more conceptual walls or a Compromise model where science bends a little bit more.

Modern battles
In 1925 there was the Scopes trial, where a Tennessee high school biology teacher was found guilty of the crime of teaching about evolution in his classroom. From then through the 1980s, evolution was a hot political issue in American politics. Early laws like the Tennessee one outlawed the teaching of evolution in some places. These were overturned or eventually ignored through the 1950s and 60s. Annoyed by the widespread teaching of evolution, Creationists pushed to get state and local boards of education to approve the teaching of their alternative side-by-side with evolution. From the 1960s to the 1980s Creationism’s influence grew and its teaching next to evolution (“equal time”) was mandated at the state or local level in many places. Creationism was finally defeated, at least formally, in 1987 when the U.S. Supreme Court struck down an Arkansas law as unconstitutional because it concluded that Creationism promoted a particular religion.

Today, Creationism has given way to Intelligent Design, which is now being pushed as an alternative to evolution in public schools in America and elsewhere. Though ID is less specific about its religious ideas than Creationism, proponents of teaching ID in a public school lost in court in Dover, Pennsylvania in 2005, where a federal judge viewed it as primarily religious in its motivation and therefore inappropriate for a public school. In Kansas a similar battle in the state Board of Education started with a 2005 policy that mandated the teaching of ID, only to be overturned by a newly-elected Board in 2007.

At the heart of all these battles is the nature of science itself, a subject that many people still misunderstand (not my reader, of course). Expect these topics to stay in the news for quite a few more years.

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44 This has nothing to do with Arthur Koestler’s use of the phrase. This does have something to do with Gilbert Ryle’s critique of René Descartes’ notion of mind-body dualism. Essentially, Descartes found it inconceivable that the mind was simply the result of the function of an organ, namely the brain. So, Descartes insisted on inventing an incorporeal mind which is separate from the body. This led him to the same sort of problem that all such dualisms face: how does the “mind” (whatever the heck and wherever the heck that is) interact with the body?

45 In the USA, educational curricula in the pre-college public schools are mostly controlled at the state or local level. Very little detail of the day-to-day curricula are mandated by the national government. The controlling bodies, the boards of education, are elected and can therefore be influenced greatly and rapidly by popular ideas.

46 In America church and state are formally separated which usually means that no government-funded initiative, like a public school, can promote a particular religion. These are very murky waters, legally, however and debates and legal cases rage constantly about publicly-funded expressions of religious ideas such as monuments to Scripture and religious Christmas displays on state property. Stay tuned!
while. While technically the only battles are whether ID or evolution, or both, are taught in public schools as science, each side is also trying to win a popular debate about how we should form our ideas about the natural world. Science as a set of physical explanations for physical phenomena is still, just barely, winning the legal battles. As you read the headlines today and tomorrow, think about the Victory, Wall and Compromise models I’ve described here. The stories you’ll read in the news will be all too familiar because the fundamental ideas don’t change.

**The Roots of Values and Morals**

Should euthanasia be illegal? Should murder? Jaywalking? How have we decided these questions in the past? How do we decide now? How should we decide? These are some of the big questions that are put under the heading of *ethics* in philosophy. Most religions also deal with questions like these, questions that center on what we ought to do. I’m not going to provide any easy answers to these questions but I will say that if answers are to be found it won’t be science that finds them.

Science uses a method that finds out what *is*. Morals and ethics and values are concerned about what *ought to be*. Mother Nature knows nothing about ought, she only does what comes naturally to her. Furthermore, science is restricted to only finding out what is about the natural world; concepts like duty, fairness, justice, crime and sin are just not on science’s radar.

But science can inform our moral and value choices. Take for example a curable mental illness that causes its victims to perpetrate violent acts on others. Before a cure was invented society may have branded such a person as a criminal or monster and locked them up or killed them to protect society. Once we know it’s a curable disease we may decide to treat them as victims and not hold them accountable, or at least accountable to a lesser extent, for their crimes. It is not science that tells society not to put them to death, it is society, informed by science, that may decide to treat these individuals differently. Another example would be the value of trees. In the past we viewed trees as resources (wood, fruit, other products) and, perhaps by some, as valuable habitats for wildlife. We may have also appreciated their beauty (something scientifically undefinable). But now that we know about photosynthesis and carbon dioxide absorption, we can value what the trees do to make our air and planet a better place.

There is a growing field called *sociobiology* that is trying to understand how some of our human behaviors, including social values and morality, came about from an evolutionary and historical perspective. In its broadest sense, sociobiology studies the social behavior of all animals in an evolutionary context. Sociobiologists assume that, at least in part, social behavior is determined or affected by genetic factors. Therefore, social behavior can evolve if it affects the survival of the species. Bees and ants are social insects in the sense that they live in densely-packed communities and individuals serve different roles in making the hive or nest function. Their behaviors are very simple and clearly dictated by chemical processes directly linked to genetics. Sociobiology makes heads turn, though, when some proponents try to apply the same thinking to human behavior.

For a hypothetical example, consider human male aggression. In most societies and in most of history, males are more likely to be physically aggressive. Why? Some have argued that it is a part of culture that gets perpetuated as parents and societies teach their children. Sociobiologists, though, look for genetic and evolutionary reasons for the aggression. Even if an “aggression gene” isn’t found, they can argue that in our evolutionary history, say in the “caveman days,” such behavior served our species well. Physically stronger males (as opposed to
females) benefit themselves and their families (and therefore their genes) if they are aggressive toward any and all threats. Let me be very clear that this has not been proven and I am just using this idea to make a point. If aggression is genetic in origin then it is naturally a part of the human male, as natural as a beard. We are then faced with the question of whether we should celebrate or punish this natural feature. Imagine a world in which men with stronger, thicker beards are automatically held to a high social status, just because of their beards! One could also imagine a very different world in which a hairy chin forces you to be imprisoned, cast out or killed. These are the kinds of questions, among others, that sociobiology asks us to consider.

Critics of sociobiology usually focus on one of two issues. The first is whether sociobiology is even possible when applied to humans. Other factors such as human culture, language and beliefs can overwhelm or at least shadow any possible genetic factors. As we have seen before, humans are very challenging subjects in any theory or experiment, even in medicine. Complex social behaviors are more challenging still.

The second issue sociobiology’s critics contend with is more important for our discussion here and, ultimately, the most important issue. *Even if* sociobiology can be applied to humans, so what? What if human males are genetically forced to be aggressive? Should that make aggression OK? We have already seen this topic in our discussion of genetics. Genetic determinism is the label for the idea that certain behaviors are controlled by genes. Actually, though, the ideas are not that rigid. What are being discussed are genetic predispositions toward certain behaviors. A predisposition is not an action, but it might affect the way we interpret, punish or reward that action. A good analogy (or a bad one, but here goes) might be the reflex to quickly pull your hand away from a hot object. This is a genetically determined reflex, but that doesn’t mean that you always have to do it. I learned that while working in a restaurant. Once, while carrying a five gallon pot of boiling hot soup, I noticed midway to my destination that one of my hands was burning because part of it was beyond the edge of the hot pad I was using to protect it. I wanted to let go but I knew if I did I would have scalded my body, and perhaps my boss’s body, with gallons of hot soup. I held on, getting a blistering burn on my hand but saving myself and others from much worse. (Also, our dinner guests that evening had three soups to choose from instead of only two!)

Again, the issue is between *is* and *ought*. *Is* is about the world, well, as it is! *Ought* is all about the world we want to live in. What we want is not determined by our genes or our history but our imaginations and ideas.

This whole discussion of morals and values is very much like the topic of technology and the use of scientific information that we met early in the book. Science can only discover the principles behind the workings of objects like radioactive elements. It is technology, scientific information wielded by value- and moral-decision-making humans, which leads some to make a nuclear reactor to generate electricity and others to create a terrifying weapon. Applied to human behavior, similar knowledge may enable some to effectively eliminate social problems and others to incite genocidal rage against minorities or foreigners.

As a final example, consider ethics and honesty among scientists. The community of scientists values truthfulness and honesty, including the fair attribution of discovery and innovation. Why? Could science advance if scientists were a bunch of lying, scheming opportunists who steal each other’s ideas and represent them as their own? Perhaps it could. Ultimately, the only true tests of a theory are the experiments that confirm or falsify its predictions. It does not matter, in principle, where the ideas come from. But it is the society of scientists that have made a moral judgment about how they will interact with one another. That’s
not a scientific law they’ve discovered, but a compact created among humans. It may be true, and I think it is, that science works better when there is honesty and fairness because scientists are more likely to invest their time and effort in their work when they know they can be rightfully rewarded for their accomplishments.

In summary, religious traditions, and other societal norms, contain lots of moral and value judgments. This is often why you’ll hear some speak of the need for religion to complement the scientific side of our humanity. I would argue that it’s not religion per se that’s needed because morals don’t only come from religion. But I would agree that we do need a source of moral and value judgments outside of science because science cannot provide them.

What Do Scientists Believe?
This is an obvious question that arises especially when debates are raging in the Victory model. Ask ten scientists and you are likely to get twelve different answers. Recently (2009) the Pew Research Center conducted some surveys to answer it, for Americans, anyway.

<table>
<thead>
<tr>
<th>Category of Belief</th>
<th>Scientists</th>
<th>Public</th>
</tr>
</thead>
<tbody>
<tr>
<td>Who believe in God</td>
<td>33%</td>
<td>83%</td>
</tr>
<tr>
<td>Who don’t believe in God, but do believe in a universal spirit or higher power</td>
<td>18%</td>
<td>12%</td>
</tr>
<tr>
<td>Who don’t believe either</td>
<td>41%</td>
<td>4%</td>
</tr>
<tr>
<td>Don’t know/refused answer</td>
<td>7%</td>
<td>1%</td>
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For this study, “scientists” were 2533 randomly-selected members of the American Association for the Advancement of Science (AAAS) which is one of the largest organizations in the world.

The data show clearly that scientists are less likely to be believers than are members of the general public. Two immediate possible explanations for this situation come to mind. The first and most common is that education in science tends to make a person lose his faith. The other is that those who are less inclined to believe are more likely to become scientists! Here we have another example of correlation without causation, and isn’t causation always the more interesting of the two? Some very religious groups tend to resist science because they fear the first scenario; that science causes doubt and loss of faith. That’s as misguided as their opponents who think that religion is necessarily contrary to science. From my personal experience I would agree with the Pew survey mentioned above. There are more non-believers among scientists but there are also devout Catholics, Muslims, Protestants, Wiccans, Hindus, etc., etc. There are also many who are still trying to figure out what they believe, or don’t believe. In this they are no different than lots of non-scientists. One of the reasons I think there is more doubt in the minds of scientists is that their everyday work can constantly confront them with issues in S&R, whereas a non-scientist may only occasionally be exposed in a news article or talk show interview. The bottom line is that the reasons behind faith (or no faith) are highly personal and vary greatly among individuals even within one scientific field or across the hall at the University or lab.

Summary
Science is newer than religion. It is natural, then, that cultures which formed around traditional religions are strained in some ways by some of the new ideas coming from science. Some, but not all. Nobody I have ever met has a religious problem with the modern theories of acidity,
kidney function, metallurgy, blood stain analysis, etc. It is only the scientific ideas that encroach on religious ideas about the physical world where there is friction.

Again, the public battles of science vs. religion reflect the inner struggles that individuals feel when faced with these issues. Do you look for Victory? Do you try to build a Wall? Do you try to reach a Compromise? Are you baffled as to which you should choose? Welcome to the human race. The Science Wilderness will be disputed territory for some time to come, perhaps forever.

References and Further Reading


Haught uses a four-category method for dividing the spectrum of interactions between Science and Religion: Conflict, Contrast, Conversation and Confirmation. I’ve used his book in a few classes, and although his “four Cs” are invariably difficult for students to remember, they are useful. My categories roughly correspond thusly: Conflict = Victory, Contrast = Wall, Conversation + Confirmation = Compromise. I consider Haught’s Confirmation to be an extreme form of compromise where discoveries in science not only inform religion but that religion motivates and inspires science. Though I think it extreme, many do espouse it. Anyway, Haught is a good writer and thinker and this is a very readable book if you want to begin a journey into the vast field of Science and Religion. Haught, a theologian and theist, is biased toward religion, and his passages on Confirmation virtually bubble with excitement. In that he is no different from me when I gush on about the greatness of science. Oh, he also does that. He has a degree in physics, too!

Barbour, Ian, *Religion and Science (Gifford Lectures Series)*, HarperOne, 1997
This is a very thorough and definitive work on S&R. A much harder read than Haught, but worth the effort if you really want to get into this subject. Barbour also used a 4-mode way of categorizing interactions between S&R and his categories, Conflict, Independence, Dialog and Integration, almost entirely correspond to Haught’s Conflict, Contrast, Conversation and Confirmation.

Numbers, Ronald (Ed.), *Galileo Goes to Jail and Other Myths about Science and Religion*, Harvard University Press, 2009
This book has myths form both sides of the S&R debate. It’s unlikely you’ll read it all but if you’ve heard or read much about S&R you will probably like 2 or 3 from the selection of 25 essays therein. Ronald Numbers is one of the best experts on the history of the debates in S&R and he carefully selected these interesting and scholarly essays.

Rolston, Holmes III, *Genes, Genesis, and God: Values and Their Origins in Natural and Human History*, Cambridge University Press, 1999. Rolston advocates a view of the natural world that has an active God involved in the process of known natural laws. Necessarily some miraculous, but mostly subtle, guidance is attributed to God in the various processes that led to humans and our place in the natural world. In a talk I heard him give he stated (and I paraphrase), “I believe God made man and I believe he did it through evolution.” The book is a reaction to sociobiologists who argue that our values and morals are derived from our evolutionary heritage.

Greek Myths:

Veyne, Paul, *Did the Greeks Believe in Their Myths?: An Essay on the Constitutive Imagination*, University Of Chicago Press, 1988

Pertinent to the Ghost in the Machine idea, Crick mentions here the trouble of finding mystical forces within the biochemical machinery of the cell. He was battling the old idea called *vitalism* which proposed the existence of a special substance or force that accounts for life, which is composed of non-living things, such as atoms and molecules. In short, Crick finds no need for this extra hypothesis to account for the phenomenon of life. Put a new name and a slightly different spin on it and the vital force (élan vital) becomes an intelligent designer. (This is a new publication of the original 1966 book from the University of Washington Press. Page reference is for the 2004 version.)

Other resources:
http://www.skepticblog.org/2010/04/05/science-and-religion-again/ outlines the methodological naturalism position against all faith-based positions, call it religion or whatever.
http://www.iep.utm.edu/sci-rel/ is a good, short overview of science and religion topics.

Pew Survey:
22. Where the Rubber hits the Road

We can now consider ourselves out of the science wilderness. The last mile or so of rutted, muddy trail has given way to pavement. Our vehicles now seem solid and safe as the tires shed the mud and dirt in clumps and spray as we accelerate. A crossroad appears and we fellow travelers will have to part ways. Once united in our predicament of being lost in a confusing tangle of scientific vines and trees and threatened by mysterious and misunderstood claws, glowing eyes and hoots in the night, we look back, no longer afraid of venturing in again to revisit a favorite waterfall, sunny meadow, stand of trees or dark cave. Now where will you go? How will your knowledge of science fact and method affect your future travels?

It is my hope that you now should be able to recognize and use the major concepts of natural science to sort through the latest news stories about scientific discoveries. The skills you acquired are not merely the recognizing of scientific terms and jargon but the implementation of a perspective about science that will lead you to quicker and easier comprehension of new scientific information. Old ideas, kept amid the cobwebs in some corner of your brain where algebra, the Treaty of Versailles and your high school locker combinations are stored, will start to come to life again with accompanying “Ah-ha!” moments, as in, “Ah-ha! That’s what my biology teacher, Mrs. Bowerman, was trying to say about photosynthesis!”

The other side of knowing the basic science is having the ability to see when people go astray when attempting to deal with the physical world using ideas or information that does not jive with how the universe actually works. As we have seen in the previous chapters, there is always conflict, controversy or failure when beliefs, traditions and policies cause people to act in ways that are contrary to what would be prudent were they informed by science. In short, if someone disagrees with well-established scientific knowledge, or uses criteria for “evidence” that deviate from rule of empiricism, and act accordingly, they will lose. Eventually, their disagreements with Mother Nature will be decided in her favor. She’s patient and merciless.

You will now be immediately aware of incoherent or incomplete information communicated about science or in the guise of science. When political or cultural issues are tied to scientific theories, you will be able to recognize the ways in which science can be misunderstood, misrepresented and misused in the pursuit of political or personal agendas. This book is more about enabling you to ask the right questions rather than providing you with all the right answers.

Now embark on your own journey, but use your jungle skills to stay aware of how science affects your life and the lives of those around you. Be wary of bad science or misused scientific ideas. Be a source of understanding and logical clarity when confusion and superstition take hold of some part of your world. You may not be a professional jungle guide, but you’re a seasoned traveler and you can certainly lead a lost tourist or two away from danger.