Ib1 – Some Basic Ideas in Science

Dear: I know that, in school, you've already studied many ideas in science, but please be patient with your old grandfather. In this chapter, I want to dig deeper, to try to show you some basic ideas that are at the foundation of all science. Thereby, I hope you'll see that these (simple!) scientific ideas are extremely important, for they form the foundation of all knowledge. And of course I realize that the last statement was a "pleonasm" (i.e., "the use of more words than are necessary for the expression of an idea", from the Greek word *pleonasein*, meaning "to be in excess"); I was just testing to make sure that, in school, you already learned that the word *science* is the Latin word for *knowledge.* (☺)

In the previous chapter I tried to show you a little about "existence theory", which in Greek and in philosophy is described as "ontology" = "existence theory". I also showed you a little of "phenomenology", which is how I maintain that most ontology should be pursued. Literally, phenomenology is the study of what appears (from the Greek verb *phainesthai* meaning "to appear"). Webster gives the following definition for 'phenomenology':

> **1.** the philosophical study of phenomena, as distinguished from ontology **2.** the branch of science that classifies and describes its phenomena without any attempt at metaphysical explanation.

In this chapter I want to show you a little about how we gain knowledge, which in Greek and in philosophy is the topic called "epistemology" = "knowledge theory" (from the Greek verb *epistanai* meaning "to understand"). For the definition for 'epistemology', Webster gives:

> **1.** the study or theory of the origin, nature, methods, and limits of knowledge.

What I will be maintaining is that this "theory of knowledge", epistemology, should also be pursued *via* phenomenology (or, in simpler terms, *via* the scientific method).

Although I want to start with some definitions (obviously!), let me mention something else. The other day, while wandering around the internet trying to learn something about shamanism, I encountered the definition: "shamanism is what shamans do." That certainly didn't help much – except to alert me to the fact that the plural of shaman isn't shamen but shamans!

But then, after I read the author's description of what shamans do, I began to see the wisdom of the author's definition. Similarly, maybe a better definition of 'science' is, not that it's 'knowledge', but science is what scientists do – and what they do is apply what's called "the scientific method." But then, it's not just scientists who apply the scientific method; therefore, science isn't what just scientists do: the scientific method is an elementary application of reason and experiments that everyone uses to gain knowledge – including small children and even animals!

GUESS, TEST, AND REASSESS

As an example, Dear, I wonder if you remember our old house near the park on the Columbia River where there always seemed to be so many seagulls – for whom you'd always want to take bread crusts, so you could chase the seagulls across the grass! When the river was low, visitors to the park would need to be careful walking across the park's parking lot, not just because of the cars, but because of those seagulls: when the river was low and the barnacles and mussels were exposed, the seagulls would pick up the mussels from the river bed, fly over the pavement of the parking lot, and drop them – to smash them open! Thus, the scientific method is what seagulls do (or the first seagull did) gaining knowledge of how to break open mussel shells!

Similarly, the first ape that used a stick to "fish" for termites, our cat who opens the cupboard door to get at her food, and a child who develops a method to get to a cookie jar, all apply the scientific method, which consists of a continuous series of obvious (but not necessarily simple!) steps:

1. Observe… that mussel shells break when dropped (either on rocks or pavement, but it's easier to find them if they're dropped on the pavement!), that termites cling to sticks, that the cat food is in the cupboard, that the cookies are in the jar… and that apples fall, that birds of the same species can have slightly different characteristics, that light travels at the same speed regardless of the speeds of either the light source or the observer (an observation that was so difficult to trust that Michelson and Morley were given the Nobel prize in physics, in 1907, for their 1887 experiments that showed this amazing property of light was undeniable), and so on.

2. Analyze, i.e., try to figure out what's going on: not very difficult for the case of smashed mussel shells, termites on a stick, cat food in a cupboard, or cookies in a jar, but Newton thought that apples might fall because there's an attraction between two masses such as an apple and the Earth, Darwin thought that birds that developed slightly different characteristics might have had a better chance to survive in an

altered environment, and Einstein thought that Michelson and Morley's strange result about light might actually reflect a property of space and time, resulting from the impossibility for observers traveling at different speeds to agree on the simultaneity of two events (which takes a while to reason through, Dear, but requires no knowledge of physics to understand, as you can see by reading Einstein's book *Relativity*,[1] which is no more difficult to read than the book you're now reading), and so on.

3. Hypothesize, i.e., from analysis of the data from the observations (for a particular case or cases) try to *generalize* sufficiently to permit predictions of what might occur in other situations: if the first mussel that was dropped broke open, then maybe the next one also would; if a stick is inserted into a termite hill, then maybe some termites would be dumb enough to cling onto the stick; if a paw is used deftly, then maybe the cupboard door would open; if a chair is moved closer to the counter, then it might be possible to get to some cookies… and if there is an attraction between an apple and the Earth, then maybe the same force of attraction holds the Moon in orbit around the Earth and the Earth in orbit around the Sun; if offspring are born with characteristics that improve their chance of survival, then maybe this "natural selection process" has caused the evolution of all life forms on Earth; if observers moving at different speed can't agree on simultaneity, then they wouldn't agree on time intervals, lengths, and therefore (after a little algebra!) energy (E) and mass (m) must be related to the speed of light (c) *via* $E = mc^2$, etc.

4. Subject the predictions to experimental tests (but I'll skip listing tests of the hypotheses listed above!), and then, to "complete" the scientific method:

- Reject hypotheses that fail their tests;

- Conditionally accept those hypotheses that pass their first test – with the condition being that they must also pass any future tests to which anyone (or any seagull, ape, cat, or child) may wish to subject them;

- State each hypothesis as succinctly as possible (which seagulls apparently do with a special "call" that must mean "Food!" and which scientists do by applying "Ockham's razor"; e.g., the statement "I think that God is everything and therefore, obviously, God exists" is "shaved with Ockham's razor" to "things exist"); and then

- Inform others about the new results (which, down by the river, means that a huge swarm of seagulls will soon be bombarding the pavement with mussels (!) and which, in science, means reporting results at conferences and publishing them in science journals), so others can check the reported experiments and data and can subject the proposed hypothesis to additional experimental tests. That is, science is a "community project", open to all – not knowledge for only "a chosen few" or "the faithful" or "the set apart".

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[1] Dear: This book by Einstein is available online at http://www.gutenberg.org/etext/5001.

And thus the scientific method continues, without end: observe, analyze the data, hypothesize, test predictions of the hypothesis experimentally, observe the results, analyze the data, report the results, etc., etc., etc.

I hope (and trust), Dear, that the scientific method seems trivially obvious and a totally reasonable way to try to gain knowledge. Richard Feynman (co-winner of the 1965 Nobel Prize in physics) summarized with the statement: "Science is a way of trying not to fool yourself."[2] In fact, the essence of science is just that, a trivially obvious and totally reasonable way to try to make sure we're not fooling ourselves.

Besides, if one ponders how seagulls, cats, dogs, and so on (including people) gain knowledge about the external world, then an obvious question is: Is there any origin of any knowledge about the external world besides *via* the scientific method? Certainly we can gain knowledge from other people (e.g., *via* books), but in every case, wasn't any knowledge originally obtained *via* observing, analyzing data, generating some hypothesis that summarized the data and that had predictive capabilities, testing the predictions, analyzing the data, and so on?

On the other hand, although the essence of science (*viz*., the scientific method) is trivial to understand, of course I don't mean that science is trivial: learning the knowledge already acquired (even within very narrow branches of study) can be extremely laborious – and learning all that is now known is almost certainly impossible for a single human. Even ~2400 years ago, one of the most brilliant people who ever lived, Socrates, reportedly said "I know nothing except the fact of my ignorance" (but one of his later statements suggested that his earlier statement was an exaggeration).[3]

Meanwhile, in modern times, such an enormous amount of knowledge has already been acquired that students must expend substantial effort (in some cases, decades of intense effort!) learning what has already been discovered, even within rather narrow branches of knowledge, e.g., in computational

[2] Feynman also stated "Observation, reason, and experiment make up what we call the scientific method", which (at many places on the internet and apparently derived from some elementary-school textbooks) I've seen reworded (crudely but nicely) as "guess, test, and revise (or instead of "revise", "find out", or "see what happens", or "guess again") method"! I would rather it were: guess, test, and reassess.

[3] In his book *Euthydemus* (which you can find on the internet and which I will be referencing later), Plato reports that Socrates stated: "I know many things, but not anything of much importance."

fluid dynamics, microbial ecology, quantum electrodynamics, etc. Such intense study, however, is for those who seek to become experts in some scientific field – which you may or may not choose to do, Dear, depending on what interests you and on how you think you'll best achieve your goals.

Yet, whatever you choose, I hope you'll apply the scientific method every day of your life. And actually, associated with that hope for you, I have very little concern – because it's essentially impossible not to use the scientific method: observe (that clouds are forming), analyze (based on current and prior observations, clouds such as those usually mean rain), hypothesize and predict ("I think it's gonna rain today"), test your prediction (and when you go to school, take your umbrella!), etc., and maybe even report on your results: "When I started out this morning, I thought it was going to rain, but it certainly turned out to be a nice day!"

But though you may agree that the scientific method is a trivially obvious and totally reasonable way to try not to fool yourself, I plan to describe its steps in more detail. That plan may seem to be a waste of your time, but please be patient with me. The scientific method is the basis of all understanding about "reality", and when you thoroughly understand what 'understanding' means, you'll see some of the huge number of enormous mistakes that people have made, fooling themselves into thinking that they understood something they didn't.

Further, as I'll try to show you, some of the most foolish and horrible mistakes ever made were made by some of the most brilliant people who ever lived (including Pythagoras, Plato, Aristotle, Spinoza, and Newton). And "closer to home" (though not suggesting that I'm not dealing with one of the most brilliant people who ever lived!), there's a certain grandchild who has been subjected to most unfortunate indoctrination, because a substantial number of people failed to apply the scientific method correctly, fooling themselves into thinking that they possessed knowledge when all they possessed was a bunch of silly speculations. And my reason for including those comments, Dear, was to try to reinforce the potential value of addressing some important questions:

- What's the difference between a speculation and a hypothesis?
- What's the difference between a hypothesis and understanding (or knowledge)?
- What does 'understanding' or 'knowledge' mean?

It will take me a number of chapters to complete my response to those questions, but in this chapter, let me try to give you at least "an overview", using an analogy (in spite of my queasiness with all analogies).

PANNING FOR KNOWLEDGE

This analogy is stimulated by the muddy river near where you know I now walk. Dear, the scientific method is like panning for gold in a muddy river. As you well know (based on your analysis of a huge amount of data!), in life we're all inundated by a seemingly unending stream of ideas. The scientific method is a way to filter the muddy river of ideas (most of which are "mere speculations"), first to collect suspended sediment (which we call "hypotheses") and then to pick through the collected sediment to find a few nuggets of knowledge (that can be called "useful working-hypotheses" or "principles" or "axioms").

Let me explore this analogy further. Consider the *set* of all things called *ideas*. Further, divide this *set of ideas* into three *subsets*, each labeled with one of the words: *speculations*, *hypotheses*, and *knowledge* (or the latter can be labeled "useful working-hypotheses" or "axioms" or "principles"). Then, the task of choosing how to label (and then treat) different ideas, within the "flood of ideas" in which each of us is immersed, the task of identifying to which subset different ideas should be associated, is like panning for gold in a muddy river during spring flood:

1) The crudest of these three concepts (as plentiful as the water in the river) is that of *speculations*. That is, in this world there are a huge number of speculations "floating around", including the speculations that all invisible flying elephants are pink and that various gods actually exist (as something beyond mere speculations).

2) The next more refined concept (almost as plentiful as grains of sediment in the muddy river) is that of *hypotheses*. That is, a huge number of hypotheses are currently "afloat", varying in usefulness in proportion to the degree to which that they've been validated, e.g., from the hypothesis that this universe started with a Big Bang (barely validated) to the hypothesis that exercise is generally good for your health (quite well validated).

3) As the most refined of these concepts, there are a relatively few nuggets of information that can be called *knowledge*, including the idea that a certain grandchild exists and that by-far-the-best way to filter thoughts into various categories is *via* the scientific method!

Let me now go through the above, again, in more detail. As the crudest types of human thought, speculations are little more than the first step in the scientific method, i.e. observations. In worst cases, sometimes these 'observations' are only what we 'see' in our own "mind's eye" – such as flying pink elephants! That speculations are little more than observations is consistent with the Latin origin of the word 'speculation'; that is, 'speculate' is from the Latin verb *specere* meaning "to see".

Yet, by 'speculation' we now mean a little more than "to see" or "to observe", namely, that we make a first guess at trying to understand what we see. For example, your easily identified ancestors in northern Europe experienced thunder and lightning and speculated that these were caused by the thunder god, *Thor*. The Ancient Greeks did similar and called the thunder and lightning god *Zeus*. And the Ancient Hebrews did similar and called their mountain and sky god *Yahweh* (mistranslated as *Jehovah*), who many in our culture (including your parents) now call [just plain] *God*. As another example, some modern (but intellectually primitive) people experience 'goodness' and 'love' and speculate that, thereby, they are "experiencing God". Similarly, when these same people experience feelings of 'evil' and 'hate' they speculate that they've "encountered the Devil".

Such speculations or guesses can range on some "guesstimate scale" from "idle speculations" to "serious speculations". In part, this range in speculations can reflect the mental energy expended creating them, but also, maybe the difference is in consequences. Thus, maybe an "idle" speculation is one that doesn't have many consequences, such as "all invisible flying elephants are pink". On the other hand, maybe a "serious" speculation is one that has serious consequences, such as "God exists", "the Israelites are God's chosen people", "black people carry the mark of Cain", "the Aryans are a superior race", "there is one god, Allah, and Muhammad is his messenger", and other such total nonsense that, with faulty logic, with no experimental tests, and with zero supporting data, have caused (and are still causing) humanity enormous harm.

Next are hypotheses. Originally, the ancient Greeks probably intended that the word 'hypothesis' was to mean 'understanding', because *hypo* is the Greek word 'under' (as in "hypodermic needle", i.e., a needle that goes 'under' the 'dermis', where *dermis* is the Greek word for skin) and 'thesis' is from the Greek word *tithenai* meaning "to place or put"; so, 'hypothesis' literally means 'underplacing' – or 'understanding'. Now, however, "to hypothesize" doesn't mean "to understand": formulating hypotheses is just one of the steps towards 'understanding' (which now means 'knowledge').

In modern use, "to hypothesize" means, in part, "to guess" or "to speculate" – but it also means much more. You can appreciate that there's more to hypothesizing than just speculating, Dear, when you hear someone say (usually as an insult): "That's mere speculation!" To be called a hypothesis, a speculation must also: 1) succinctly summarize some data, 2) be logical (which, as I'll show you in the next chapter, means to be consistent with some fundamental principles about nature), and 3) have the potential to lead to predictions that can be tested experimentally. In addition, if a new hypothesis is to have some reasonable chance of being considered seriously, it shouldn't conflict with ideas that have already been established as 'knowledge' or 'understanding' (shortly to be described).

Finally in these three subsets of the set of all things called 'ideas' (i.e., in the trio: speculation, hypothesis, and knowledge), there's the concept of 'knowledge' or 'understanding'. To explain fully what 'understanding' should mean will take me quite a while (and will include material in **T2**, entitled "Truth and Understanding"). For now, I want to rely just on your own concept of 'understanding' plus add the following.

Dear, we can justifiably claim some knowledge (or understanding) of some thing or process when we have a "useful working-hypothesis" dealing with the thing or process. To be a "useful working-hypothesis", a hypothesis must not only succinctly summarize a substantial quantity of data, be logical, be consistent with other useful working-hypotheses, and lead to testable predictions (as must all hypotheses), but also, to be a useful working-hypothesis, its predictions must already have passed every carefully performed test that anyone has subjected it to. That is, we begin to gain understanding of some thing or process when our hypothesis about it yields predictions that pass experimental tests – and the more tests that our hypothesis pass, the more confident we become that our "useful working-hypothesis" represent a true "nugget of knowledge".

Thus, Dear, using the scientific method, we can filter ideas, separating "nuggets of knowledge" from the gravel, sediment, pollution, etc. in the general flow of idea. As I hope to show you in subsequent chapters, this use of the scientific method to "filter" ideas is extremely important. Using it:

- We can reject (and should reject) hypotheses (or better, "just speculations") that have no observational support (such as "all invisible flying elephants are pink"),

- We can reject (and should reject) all speculations and hypotheses that conflict with knowledge already gained (such as, "all… flying elephants…", because elephants, on their own, can't fly),

- We can reject (and should reject) all speculations and hypotheses that are illogical (such as "all invisible… are pink", because if they were invisible, how could their color be determined?),

- We can reject (and should reject) all speculations and hypotheses that can't be tested (e.g., such as "all invisible flying elephants are pink" – unless, of course, someday someone captures a herd of invisible flying pink elephants – and discovers a way to determine their colors!), and as already mentioned,

- We can reject (and should reject) all hypotheses whose predictions fail their experimental tests.

Now, Dear, I trust you expect that I'll give you more details about how to filter ideas using the scientific method. You "know" (you've observed, hypothesized, predicted, and validated your predictions with multiple tests) that your old grampa can "drive you up the wall" with such details! Yet, before then, I want to show you one of the simplest ways to test if a proposed hypothesis is anything more than "mere speculation". It's commonly called "the snicker test".

THE SNICKER TEST

Although it's not always a reliable method, the "snicker test" is commonly used and can be used with amazing effectiveness. Thus, if people start snickering (or laughing or jeering!) when they hear some idea, then the idea is probably "mere speculation". In turn, the snickers, jeers, and laughter can be directed at any of a number of foolishnesses in the speculation. For example, if a little boy claims to be able to fly to the moon by flapping his arms, then the jeers from the other children is their way of saying: "your speculation summarizes no data", or "your speculation is illogical", or "let's see you perform an experimental test of your hypothesis."

Unfortunately, though, the "snicker test" isn't very reliable, for any of a number of reasons.

- In some cases, the proposed hypothesis can be so complicated that it's difficult to discern if it's illogical; in a later chapter, I'll show you some (complicated!) examples.

- In other cases, the proposed hypothesis can be too horrible to induce any light-hearted reaction such as snickering: some examples are the horrible hypotheses (or, better, "mere speculations") of racist groups (such as the Ancient Hebrews, the Nazis, the Klu Klux Klanners, the Mormons, and many others) who proposed that the traditions, culture, religion, skin color, eyelid appearance, or whatever, reflected an inherent "worthiness" of humans (or their "purity", or whatever other garbage-word has been used – and is still being used). For such cases, more than snickering (or laughing or jeering) is needed to debunk such stupid speculations; in some cases, it has been necessary to go to war to stop their horrible consequences.

- Fear (e.g., of being hurt, of being ostracized by the group…) can also be used to squelch any snickering. That is, "the snicker test" also fails if the group that proposes the wild speculation has sufficient power to instill fear into any who would dare to laugh at the absurdities of the speculation. If people are afraid of thunder and lightning, for example, and if a solemn shaman proposes a ridiculous speculation to alleviate the fear [such as, "the thunder God *Thor* (or *Zeus* or *Yahweh* or *Allah*) is thundering against your transgressions of His law"], then the ridiculous speculation may not be laughed out of existence because of the people's fear. If people are afraid because their way of life is ending and if a solemn cleric says that, although the world is coming to an end, he can save them and give them eternal life, then even such a ridiculous speculation has a chance of not being laughed at, because of the people's fear. In fact, I wouldn't be surprised if fear is the dominant reason why essentially all religious ceremonies are solemn, with the only "joy" permitted being the "joy of believing".

Thus, Dear, even some absurd speculations can be constructed in a manner to inhibit people from bursting into laughter. One way, common in history and still practiced in many Islamic countries, is to make people so terrified of those in power that the people will "believe" whatever their leaders require. For example, when the Christian Church proclaimed that the sun revolved around a flat earth and tortured or murdered those who thought otherwise, few people laughed. Another way, still common in many societies, is to capitalize on some foolishness of the people: the now classic example is Hans Christian Anderson's story about the con artist who sold the king beautiful garments that could be seen only by "the worthy".

And still another way to "sell" absurd speculations, without the potential buyers bursting into laughter, is the method used by all organized religions: first indoctrinate the children, and when the children are grown (at least in stature), always refer to the "basic beliefs" with much pomp and ceremony –

and solemnity. This method is used by all organized religions, because otherwise, too many people would burst into laughter at the mystics' claims that they know the unknown! Thus Dear, I no longer enter any church, in part because I expect that I couldn't control my laughter – save by the sadness that I expect would come over me, realizing how many people have been hoodwinked by such charades.

For example, when religious leaders preach that their god parted or walked on some water, then snickers and jeers that would summarize "your speculations is inconsistent with what is known about nature" are not heard, because those who would ordinarily start snickering or laughing, are afraid of the consequences. And when religious leaders preach that their god will give people eternal life (or even their own "godship"), then snickers and jeers and laughter that convey the idea "your hypothesis summarizes no data" aren't heard, because the people have succumbed to their fears, including the fear (preached by these same religious leaders) of "eternal damnation" – for laughing! As Voltaire (François Marie Arouet, 1694 – 1778) said: "God is a comedian playing to an audience too afraid to laugh."

All clerics have learned that snickering, jeers, and laughter must be squelched. Laughing at the silliness (the idiocy!) preached by clerics is strictly prohibited. It's as if, on every door of all "religious indoctrination centers" (also known as "churches", "mosques", or "synagogues"), there's posted a "happy face" with a diagonal line through it – meaning, "no laughing"! Of course the "faithful flock" are taught differently. They are taught by the clerics that they can gain knowledge through "faith", that they will understand if they just "believe". In contrast, in a tremendous collection of quotations assembled by Wayne Aiken (a collection that I'll use many times in this book, that's available on the internet,[4] and that I'll refer to as "Aiken's collection"), there's the following stimulating statement by Steve Eley (about whom Aiken gives no additional information):

> Invisible Pink Unicorns [or Elephants!] are beings of awesome mystical power. We know this because they manage to be invisible and pink at the same time. Like all religions, the Faith of the Invisible Pink Unicorns is based upon both logic and faith. We have faith that they are pink; we logically know that they are invisible because we can't see them.

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[4] At http://www4.ncsu.edu/~aiken or (in two parts) at http://htomc.dns2go.com/atheism/cookie.41a and http://htomc.dns2go.com/atheism/cookie.41b.

Now, Dear, please "rest assured" that I'll return to examine other methods to test hypotheses (besides the commonly used but not very reliable "snicker test"). But before I start digging into such details (some of which require a lot of digging!), let me comment a little more on one of the filters that I've already mentioned several times but not adequately explained, namely, the importance of "succinctness", or equivalently, the value of "shaving superfluousness" with Ockham's razor (also spelled as "Occam's razor").

OCKHAM'S RAZOR

Actually, about 1600 years before William of Ockham (who lived in England from about 1288–1348), Aristotle hinted at the importance of succinctness in formulating any hypothesis. In his *Metaphysics* (Bk. VIII, Pt. 6) he began guessing about how many "prime movers" (i.e., gods) there must be and concluded:

> When the consequences of either assumption are the same, we should always assume that things are finite rather than infinite in number…

Usually, though, a more succinct and powerful version of this idea, known as Ockham's razor, is applied: "Entities should not be multiplied unnecessarily" – or in the Latin in which he wrote: *"Essentia non sunt multiplicanda praeter necessitatem."* He also wrote: *"Frustra fit per plura, quod fieri potest per pauciora";* i.e., "It is vain to do with more what can be done with less." In more modern language, Ockham's razor simply means: Simplify! In particular, among a set of equally plausible hypothesis, first investigate the simplest.

Yet, Dear, I should add that there's no "proof" that Ockham's razor is "true", just as there's no "proof" that anything dealing with reality is "true" (which is a subject I'll get to in the two **T**-chapters, both of which deal with the concept of "Truth"). Instead, Ockham's idea is just the recommended (and obvious) procedure (or principle): when you're trying to understand something, start with the simplest hypothesis that's consistent with all relevant and reliable data. For example, when Einstein first derived his equations of general relativity, he was stumped because he had no idea for the value of a particular constant; so (seeking simplicity), he chose to investigate the simplest case first, with the constant taken to be zero. This assumption gave him Newton's result for gravity.

Similarly, Dear, if you can't find your shoes, don't start from the assumption (which may be correct) that an international industrial spy ring has stolen them to copy their design, or from the assumption (which may be correct) that your sisters buried your shoes in the backyard as retribution for your maltreatment of them, and so on. Instead, start with the simplest hypothesis consistent with the data: you forget where you left them! Of course, after you have spent a full minute in one of your famously thorough searches of all available places you might have left them, then by all means complain to your parents that your sisters buried your shoes in the backyard – and if they doubt that hypothesis, then certainly call in the FBI!

Seriously, though, Dear, Ockham's razor is important, because our minds do have a "natural tendency" to go "flying off in tangents". Stated differently, Ockham's razor says: "Constrain yourself!" – or more appropriately, constrain your thoughts.

I trust that you're thoroughly familiar with the way our minds take off on "flights of fancy", from speculations about what happened to our shoes to speculations about how the universe was created. No doubt there were (and still are) advantages to our survival to have such active imaginations (some things that went "bump in the night" may really have been tigers, lions, or other monsters!), but when it comes to trying to understand nature, then apply Ockham's razor. As Francis Bacon said approximately 400 years ago: "We must not then add wings [to our imagination] but rather lead and ballast…" if we are to identify useful working-hypotheses. And let me add: the best known "lead and ballast" to constrain our flights of fancy is reliable data.

GENERALIZATIONS FROM DATA

But moving beyond those two simple methods for trying to formulate hypotheses (*viz*., the snicker test and succinctness), let me turn to one of the most important "nuggets of knowledge" that you've undoubtedly already found, a nugget that's important enough to be called a general principle and that's learned (of course!) through application of the scientific method (i.e., by observing, analyzing, hypothesizing, and testing your predictions). It deals with understanding, itself. The general principle is that it's very difficult to establish general principles! Stated differently: *one of the few generalizations that can be trusted is that few generalizations can be trusted!*

Observations

Another generalization that can be trusted is that all understanding must rest on a bedrock of observations, where by 'observations' I mean not only what can be seen but also what can be detected with any of our senses or with instruments that have been developed to extend our senses. Because observations are so fundamental to understanding, we must always do our utmost to promote honesty in reporting observations, and then, when we learn about someone else's observations, we should still be skeptical – because someone may be quite honest but report false results from deceptive observations or faulty measurements. In addition, what's observed could be staged, any measuring instrument can mislead, reports of observations have been notoriously deceptive, even our eyes can deceive us, etc. Further, unfortunately there are cases when dishonest people lie about observations; for all cases, we should ask if the observer is 'objective' or if the observer profits from the reported observations.

Meanwhile, though, modern life is so complicated that, in many cases, we must rely on someone else's observations (e.g., "the infection in your throat is a staff virus", or "a hurricane is approaching your state", or "this quarter, the earnings of our company are…"), but those reporting such observations need to earn your trust, and if the matter is important enough to you, Dear, then you should explore further the reliability of their observations. In fact, even though you may trust your doctor, if she should report that you have a malignant growth, then you should seek additional analyses, to make sure that no (honest) mistake has been made.

As for "dishonest data" (caused by anything from faulty observations to fraudulent reporting, in turn caused by anything from incompetence to deliberate deception), the best protection you have is your own constant shield of skepticism. For example, if some fellow reports to you that he was visited by an angel who said that you should… [whatever], then I suggest that you thank him for reporting the observation to you – and then quickly seek more trustworthy companions. My point, Dear, is simply that the bedrock on which any understanding rests is data from observations; therefore, if you are to develop understanding upon which your decisions will rest, then do the best you can to ensure that relevant data are reliable.

Interpretations

But enough about observations. Now, I want to turn to the second step in the scientific method, namely, analysis or interpretations of the observations, commonly described as "trying to make some sense of the data". This step is extremely important, probably the step that causes scientists most difficulty – and the step where the Newtons, Darwins, and Einsteins of the world begin to be separated from the rest of us!

To illustrate the difficulty of this step, Dear, I could give you several examples from my own scientific career (both of my own errors and the errors of others), but I'm afraid that the explanation of each would require too much space. Instead, I'll try to generalize. A few concepts that I've learned from analyzing data in science and that might be useful to you in "every-day life" are the following.

- *Never forget the "true nature" of the data.* What can easily happen in science (especially as measuring instruments become more complex) is that we easily forget what was actually measured (even in those cases where there is little-to-zero doubt that the instruments are operating properly): an instrument may correctly measure pressure, electric field, radioactivity, or some other quantity, but the quantity actually measured (e.g., gamma rays from some shielding) is not what the scientist thinks was being measured (e.g., gamma rays from some target); as a result, the reported interpretation of the data can be totally wrong.

  A case of which you might be aware is the one dealing with "cold fusion": there's little doubt that the two scientists involved measured "excess heat", but their interpretation that this heat was from nuclear fusion was almost certainly wrong. The same type of misinterpretation is common in life: throughout recorded history, there probably have been millions of reported "messages" and "signs" from various "gods"; in each case, however, the "true nature" of the data was that an electrochemical signal was processed in someone's brain (perhaps caused by something that the person ate for dinner!), or an earthquake occurred, or that a bird was circling on one's left rather than on one's right, etc. Again, Dear: if one is to understand what any data mean, one should never read into them more than was actually observed.

- *Be honest, be objective, be inclusive – don't let your "wishes" whitewash the data.* This principle may seem to be too obvious to be listed, but during my career, many times, I was amazed to find that even "objective" scientists selected data that supported their views, while disregarding data that didn't – almost certainly without realizing their biases. Meanwhile, outside the laboratory the practice is blatant: from cases supporting preconceived views that another person is "good" (or "bad") or that a group of people is "superior" (or "inferior") to a huge number of cases in various religions.

An illustration in a religion that's so absurd as to be laughable (were it not for the many lives damaged) is the "belief" by members of the Church of Jesus Christ of Later Day Saints (LDS or "Mormons") that some of the "lost tribes of Israel" populated the Americas in about 600 BCE, left a record of their experiences about 1,000 years later, and then, after about another 1,000 years or so, one of God's agents gave this record ("the Book of Mormon") to the "prophet" Joseph Smith – one of the most successful con-artist "profits" who ever lived (even though records of his personal life show that he practiced fraud all his life, starting with "finding" buried treasures when he was a boy). In this case, there isn't a single shred of archeological data that supports (and much data – including from DNA analyses of skeletal remains – that totally refute) the Mormon's "belief", yet apparently there are millions of Mormons in this country who say (in effect): "Never mind the data, my mind's made up!"

- *Don't read more into the data than is actually there; seek simplicity, not complexity.* In later chapters, I'll show you some examples of people reading far, far more into the data than the information actually contained. Here, let me just mention a mistake that so many people make (including those trained as scientists), a mistake that a Stanford statistics professor (I never knew his name) summarized (in not very good English!) with: "Correlation doesn't mean causation!"

  What commonly happens is that someone finds that two sets of data are highly correlated (meaning that trends in the data are very similar), and although in many cases a high correlation does suggest that there is a causal relation (e.g., there is a high correlation between the blackness of clouds and the amount of rainfall – because normally a cloud's opacity is an indication of its liquid-water content), there are other cases where a high degree of correlation is a reflection of a common variable or it's just a statistical aberration. For example, on a hot sunny day, there is a high correlation between how hot you feel and the height to which the mercury climbs in an outdoor thermometer (because both depend on the temperature), but how hot you feel don't make the mercury rise in the thermometer! And there may be a high correlation between what someone "prays" for and what is achieved, but "correlation does not mean causation".

But enough of that for now. Now, let me get closer to what separates the Newtons, Darwins, and Einsteins of the world from the rest of us, namely, the insight to discern one or more general principles given data for only a few particular cases. Later, I'll show you some examples, but before doing so, I want to point out two essential features of such generalizations.

Generalizations

The first essential feature, Dear, is that *no scientific generalization is ever proposed to be true!* No, Dear, that's not a "typo"; yes, Dear, it's what I mean!

Correspondingly, no scientist accepts Newton's principles of motion, Darwin's theory of evolution, Einstein's theory of relativity, or any other scientific principle as "true"! All generalizations are proposed only as hypotheses, whose predictions are then to be subjected to whatever experimental tests anyone desires – and is capable of executing.

The second essential feature of scientific generalizations is the recognition that *no hypothesis can ever be shown to be true* – and then, of course, it's highly convenient [: >;] that no scientist ever claims a generalization to be true! Thus, Dear, the best we can ever achieve are hypotheses that seem to be approaching "truth" or, stated differently, the probability that some hypothesis is true (which is a topic to which I'll repeatedly return, e.g., in the **T**-chapters dealing with "Truth").

THE PRINCIPLE OF CAUSALITY

Now, let me get back to the step in the scientific method of making generalizations or "postulating hypotheses". In later chapters, I'll give at least some outlines of how some important scientific principles were conceived (including those conceived by Newton, Darwin, and Einstein). Here, though, I want to start with what is probably the most important scientific principle ever conceived, by someone unknown, tens of thousands of years ago. It's known as *the principle of causality: the generalization that all effects have causes.*

Now, Dear, although I've already mentioned this principle of causality in earlier chapters (several times!), please consider it once again – because it's a stunningly important scientific principle, and after tens of thousands of years of testing this principle, essentially every one agrees that it seems to be approaching "truth". During the past 100 years, a few refinements have been added to it (in quantum mechanics and chaos theory), but these refinements (which I'll outline later) are minor compared with the sweeping grandeur of the principle of causality. It's upon this principle that the entire superstructure of science has been built: whenever a new hypothesis in science is proposed, embedded in it is the assumption that all effects have their causes. More significantly, it is upon the principle of causality that all knowledge about reality rests.

Further, Dear, I hope you notice that most animals possess at least partial knowledge of the principle of causality: they seem to recognize that particular effects have their specific causes. For example, when I would go to feed our old German shepherd, upon his hearing me coming and/or smelling the food and/or seeing it, he would start leaping around – but never leaping up on me, seeming to know the routine that, provided he didn't interfere with me and spill the food, the set of causes (heard, smelled, seen, and so on) would lead to the effect of food appearing in his dish. In contrast, when I'd go to take him out in the desert, when he heard (or saw or whatever) the rattle of the choke chain on his leash, he'd start jumping up at the gate, backing off when I went to open it, apparently knowing that those set of causes led to the effect: we're off for a walk in the desert!

Similarly, other animals seem to know that specific causes lead to specific effects, just as our cat learned to open the cupboard door with her paw. And maybe animals know even more. Most animals (maybe all animals) seem to know that all sounds and smells and sights have causes: a generalization that their ancestors had to make to alert them to dangers to their survival. That is, those animals that didn't learn how to make such a generalization are extinct.

But somewhere in our distant past, human animals went one-step further in this generalization process, not only hypothesizing that all sights and sounds and smells have their causes, but hypothesizing that everything has its cause. If we did not trust this fundamental principle of causality, there would be no hope of understanding – save to understand that nothing could be understood. All knowledge relies on correctly applying this principle of causality to our observations, a principle that "Mother Nature" has been teaching each-and-every-one of us almost since the day each of us was born.

The assumption that all effects have their causes was formerly called the "*law* of causality", but it's now called the "principle of causality", because modern scientists no longer describe any generalization as a "law". That is, Dear, be aware of a change in terminology that has occurred during the past half-century or so. Although you may have been taught about "Newton's <u>laws</u> of motion" and about the "<u>laws</u> of thermodynamics", be aware that this terminology is now antiquated; nowadays, these should be called "Newton's <u>principles</u> of mechanics" (including his *incorrect* "second law" of motion!) and "the <u>principles</u> of thermodynamics" (including the *incorrect* "first law", if it doesn't include transformation of mass into energy).

It's also common to use the word "theory" to describe a group of related principles (such as Darwin's theory of evolution, thermodynamic theory, electromagnetic theory, the theory of quantum mechanics, and Einstein's theories of relativity). These "principles" and "theories" are summaries of information that scientists throughout the world have tried so hard and so long to prove incorrect that only a few "diehards" are still trying to prove them wrong.

More power to the "diehards"! If someone can demonstrate that an important principle or theory of science is wrong, then that someone will almost certainly win a Nobel Prize. During the last 30 years of his life, Einstein was a "diehard disbeliever" in quantum mechanics, but was unable to convincingly demonstrate that the theory was wrong. And although I doubt if many scientists (if any!) are actively trying to demonstrate that the principle of causality is wrong, some of the most amazing accomplishments of twentieth-century science were to demonstrate some of its limitations. In prior centuries, as far as I know, this principle was never doubted, although certainly it was recognized that sometimes the links between cause and effect were so complicated that they were almost impossible to decipher. During the twentieth century, two theories (quantum theory and chaos theory) bumped into some limitations of the causality principle, almost by accident.

As I'll show you in a little more detail in a later chapters (in **S**, dealing with Science, and **U**, dealing with Uncertainty), early-1900 studies of the submicroscopic world of molecules, atoms, and their constituents (i.e., studies in quantum mechanics), by Plank, Einstein, Born, Schrödinger, Heisenberg, Dirac, and others, demonstrated that, at these submicroscopic scales, cause and effect are related only probabilistically: given any cause or process, the best that we'll ever be able to do is describe the probability of various outcomes or effects. And as I'll also show in a little more detail later, studies with a variety of "nonlinear systems" (i.e., those systems for which if the cause is doubled, the outcome can be more or less than doubled), by scientists such as Poincare, Liaponoff, Lorenz, and others, demonstrated that, at a great variety of spatial scales, any uncertainties in initial conditions (no matter how small) grow so large that it then becomes impossible to determine the outcome: for example, the motion of a single grasshopper in the African Sahara can lead to hurricane hitting Florida.

But I won't need to use such complications in the principle of causality to demonstrate that "the god idea" is bad science; so, I'll set such complications aside until later chapters. On the other hand, I do want to use some basic ideas in logic, which will be the subject of the next chapter. Meanwhile, Dear, why don't you perform your own test of the hypothesis that getting some exercise is good for you?!