2

Observation

MAKING ACCURATE OBSERVATIONS

The key to solving most problems is to pause and carefully sort through what we know and don't know about the matter at hand. It should come as no surprise, then, that making careful observations of what is (and is not) the case lies at the heart of scientific method. Consider, for example, the many roles observation plays in coping with a small puzzle I encountered not too long ago.

One morning I awoke to the sound of a loud "rat-a-tat-tat" coming from my living room. What I discovered was a small bird incessantly pecking on one of the windows. I knocked on the glass and the bird flew off but within a few minutes was back at it again. I rapped on the glass again with the same results. I went outside and shooed it away. But within a few moments it was back at it again and continued to make the same by now quite irritating "rat-a-tat-tat," occasionally flying off for a few moments but always coming back. At this point I surveyed the surroundings. What could this persistent little bird be up to? The first thing I noticed was that directly inside the window where it pecked sat a vase of bright orange dried flowers. Maybe, I thought, the bird is trying to get at dinner. So I moved the vase to another room. The bird didn't miss a beat. Maybe, I thought next, there is something on the glass the bird is eating. Even though I couldn't spot anything, I scrubbed the glass just to be sure. Within minutes, my foe was back at it. But then I noticed something interesting. On the patio outside my living room sits a bright, shiny flower pot. Every now and then the bird would leave the window and peck on the pot. It dawned on me that it might be reacting to its reflection! So I draped an old sheet over the window and, miraculously, the bird stopped pecking. Alas, he continued to attack the flower pot and then began pecking on another window. Though the story continues through several days of pecking and many failed attempts at driving the obsessed bird away, I'll not bore you with the details. It turns out that my nemesis was a male spotted towhee, that it was Spring—when towhees mate—and that he most likely mistook his reflected image for a competitor whom he was avidly trying to chase away. (Many thanks to the local Audubon Society for clearing up this little mystery.)

My first observation—seeing the towhee—enabled me to figure out what was causing all the racket. Subsequent observations suggested possible explanations for his strange behavior—the position of the flower vase and the fact that the towhee pecked on other shiny surfaces. By observing how he behaved when my explanations were put to the test—continued pecking after the vase was moved and migration to other areas when the window was covered—I was able to rule out the former explanation and to see that the latter was at least on the right track.

In science, the art of making accurate observations serves the same three roles. First, observation can enable us to identify and focus in on the relevant facts about the phenomena under investigation. Second, what we observe can provide clues as to what might explain the phenomena. Finally, observational data can provide the evidence by which we can determine whether various explanations succeed or fail.

Unfortunately, fruitful observation is not always simple and straightforward. We may not know which data will be relevant to the solution of a particular problem and even when we are clear on this we may encounter difficulties in accumulating the observational data.

Suppose you were to pause for a few minutes and try to list all of the objects in your immediate vicinity. Before beginning, you would do well to resolve a number of issues. The first involves the fact that it is not all that clear what qualifies as an object nor, for that matter, what it is to be in the immediate vicinity. The book you are reading is undoubtedly an object. What of the bookmark stuck between its pages? No doubt the picture on the wall qualifies. But what of the nail on which it is hanging? And how should we fix the limits of the immediate vicinity? Do we mean by this the room in which you are sitting? Everything within a 10-foot radius of you? Everything within reaching distance? Even after we have settled on working definitions for these key terms, we face an additional problem. Doubtless you are likely to miss a few things on your first visual sweep. So we need to find some way to guarantee that we have included everything that fits into our two categories.

In general, the process of making a set of observations must be sensitive to a number of concerns, two of which are illustrated in the case above.

1. Do we have a clear sense of what the relevant phenomena are?
2. Have we found a way to insure we have not overlooked anything in the process of making our observations?

These two questions can usually be addressed in a fairly straightforward way. Some careful thinking about how key terms are to be applied will settle the first. In science, the business of specifying how observational terms are being used is no trivial matter. Recent scientific studies have reported findings about smokers, left- and right-handed people, and people who attend church. Do cigarette smokers have higher rates of cardiovascular disease than nonsmokers? Do right-handed people live longer than left-handed people? Do people who go to church enjoy better health than those who do not? Data relevant to these questions cannot be collected until key terms are clarified. What exactly constitutes a cigarette smoker? Anyone who has ever smoked a cigarette? And what of people who have recently stopped smoking? Are they smokers or nonsmokers? Is someone who writes with the right hand but throws with the left to be classified as right-handed or left-handed? What of older people who were taught to be right-handed even if their natural tendency was to be left-handed? Just how often must one attend church to be considered a church attendee? Without a clear sense of how these key terms are being used, subsequent research cannot get off the ground.

Keeping a written record of what is being observed will often satisfy the second concern. How many objects in your immediate vicinity? Once you have decided what constitutes an object, make a list of the objects found in a first set of observations and then add in any overlooked items from a second set. Or ask someone else to check your results. The need for a written record is all the more crucial because of the natural temptation to think we can do without one. Try, for example, to think how many times today you have done something commonplace like, say, sitting down or opening your wallet or saying "hello." Recollection will undoubtedly turn up a number of instances. But our memories are fallible and we are likely to miss something no matter how confident we are that we have remembered all the relevant cases. The solution is simply to keep some sort of written tally.

Observations are not always undertaken with a clear sense of what data may be relevant. Think, for example, of a detective at the scene of a crime. What small details need to be noted or perhaps preserved for future reference? On a long and turbulent sea voyage in 1882, many of the ship's passengers were afflicted with seasickness. One who was not was the American philosopher and psychologist, William James. James had the great good fortune to notice that 15 of the passengers, all of whom were deaf and mute, were completely unaffected. James speculated that seasickness must be due to some temporary disturbance of the inner ear, a problem to which the deaf mutes were not susceptible. Later experimentation, some carried out by James, confirmed this suspicion. This crucial clue about the causes of seasickness came thanks to James's ability to see the importance of something interesting that others had overlooked.

A set of observations may yield unanticipated information—data that does not conform to the observer's sense of what is relevant—but information that is nonetheless of some importance. Recently, medical researchers at a large university were studying the effect of calcium on pregnancy-related high blood pressure. Though they observed no significant reductions in the blood pressure of the women in their study who took calcium, they did notice something quite interesting and unexpected. The women in their study who took calcium during pregnancy had lower rates of depression than those who took a placebo instead of calcium. As a result, the researchers began an entirely new study, one designed to determine the extent to which calcium can prevent depression in pregnant women. As this example suggests, it is important not to become too attached to a fixed notion of what may constitute relevant observational data. Otherwise, we run the risk of missing something that may turn out to be significant.

One subtle impediment to accurate observation stems from a fact now well documented by psychologists. We tend to overlook a good deal of what happens when we observe an event. Psychologists have, for example, shown that we are susceptible to what is called *change blindness*. Changes in our visual field that are not signaled by flickers of movement and other attention-grabbing signs of change tend not to be noticed. In one demonstration of change blindness, observers were shown a picture of a Paris street scene. Over the brief time period when subjects were looking at the picture, the color of a car, prominently displayed in the foreground, gradually changed from blue to red. Subjects overwhelmingly failed to notice this change in color. When the color change was pointed out, observers were amazed that that they could have failed to notice the change. A related phenomenon is known as *inattentional blindness*. When we direct our attention to a particular feature of the events we are observing, we are likely to overlook other features even when they are quite obvious and pronounced. In one experiment observers watched a video of a basketball team passing the ball about. The subjects were asked to count the total number of passes. While the scene unfolded a person dressed as a monkey entered, walked among the players, beat his (or her) chest and then exited. At the end of the experiment, subjects were asked if they noticed anything unusual. Very few reported seeing anything out of the ordinary! Then, when asked to watch the tape again, those that had noticed nothing unusual were astonished to see the events they had missed in the first viewing.[1]

The lesson to be taken from these experiments should be clear. When undertaking a set of observations, we should always stop and consider the following. By focusing in on certain aspects of an observational scene, have we managed to miss something that may be relevant? By being aware of the extent to which subtle perceptual changes and inattentional blindness can cause us to miss things, we may just be able to discover information that would otherwise have escaped our attention.

Often in science, a set of observations will be prompted by the need to learn more about something that is not well understood. Recall one of our earlier examples. Not too long ago researchers uncovered what seemed to be a curious fact. On average, right-handed people live longer than left-handed people.[2] To begin to understand why this is the case we would need to search carefully for factors that affect only the left-handed (or right-handed) and which might account for the different mortality rates of the two groups. When, as in this case, observations involve phenomena that are not well understood, three additional concerns may need to be addressed.

3. What do we know for sure? What is based on fact and what on conjecture or assumption?
4. Have we considered any necessary comparative information?
5. Have our observations been contaminated by expectation or belief?

Box 2.1 How Good Are Your Powers of Observation?

We observe things every day that we scarcely notice. How many of the following questions can you answer?

1. In which direction do revolving doors turn?
2. When you walk, do your arms swing with or against the rhythm of your legs?
3. What are the five colors on a Campbell's Soup label?
4. In which direction do pieces travel around a Monopoly board, clockwise or counterclockwise?
5. On the American flag, is the uppermost stripe red or white?
6. In Grant Wood's painting "American Gothic," is the man to the viewer's left or right?
7. In which hand does the Statue of Liberty hold her torch?
8. Which side of a woman's blouse has the buttonholes on it, from her view?
9. How many sides are there on a standard pencil?
10. Does Lincoln face to the left or the right on the penny?

Answers are given at the end of the chapter.

Rarely will the answers to these questions come easily or quickly. Consider what may be involved in dealing with each.

What do we know for sure? What is based on fact and what on conjecture or assumption? Have you ever noticed that the full moon often appears appreciably larger when it is near the horizon? As you read this you are probably imagining a large, yellowish-orange moon. You've probably also heard others comment on this phenomenon. But appearances can be deceiving, opinions wrong. In fact the moon is not appreciably larger when near the horizon. This can be determined by a simple set of observations. The next time the moon seems unusually large, stretch your arm as far as it will go and use your thumb to measure the moon's diameter. Make a note of how big it seems and then make a similar measurement when the moon is overhead and apparently much smaller. You will find that its diameter is about the same in both cases. What makes the moon appear larger in the former case is its close proximity to other objects near the horizon. When we judge the size of the moon by reference to other objects—objects not near the moon when it is overhead—we mistakenly conclude that its image is larger.

As this example illustrates, it is always worthwhile to pause and think about any assumptions we may be making about the phenomena under investigation. Don't let unwarranted assumption masquerade as fact. Always ask: What do I really know about the phenomena under investigation and what am I assuming based on what I have been told or have heard, read, etc? The answer to this question may point you in the direction of observations you will need to make to test whatever assumptions you have unearthed.

Robert Park, physicist and author of *Voodoo Science*, recalls that as a child he was told by his father that raccoons always wash their food because they do not have salivary glands. One summer, Park fed dog biscuits to a family of raccoons and soon realized that the raccoons salivated upon hearing the rattling of the dog biscuit bag; saliva literally dripped from their jaws. Park quickly realized that what he assumed to be true was in error. As it turns out, raccoons do have salivary glands. Often, it seems, we can sort fact from fiction simply by taking time to look and see what is going on rather than implicitly trusting whatever assumptions we may bring to the investigation.

Beware of the assumptions innocently embedded in loaded explanatory questions. A loaded question is one that cannot be answered without accepting as true something the question assumes. "Have you stopped using cocaine?" Either answer assumes that you have used cocaine. "How" and "why" questions can tempt us to accept as true that which we are asked to explain. "How does mental telepathy work?" "Why do lemmings commit mass suicide?" Before trying to explain the phenomena in question we would do well to think about the underlying assumption. In fact, mental telepathy has yet to be demonstrated and there is no evidence that lemmings commit mass suicide.

Have we considered any necessary comparative information? Many people claim that strange things happen when the moon is full. One interesting and curious claim is that more babies are born on days when the moon is full or nearly full than during any other time of the month. What observations would we need to make to determine whether there is anything to this claim? Certainly we would want to look at the data pertaining to the number of births when the moon is full. But this is only part of the story. We would also need to look at the numbers for other times, times when the moon is not full. If the birth rate is not appreciably higher when the moon is full, then there is little remarkable about the claim at issue. Lots of births occur when the moon is full. But then lots of births occur during all phases of the moon. Indeed, careful studies done at a number of hospitals reveal that there is nothing unusual about the birth rate when the moon is full. When birth rates were examined over the period of a year or two, it turned out that, on average, there were no more or less births during the period near a full moon than during any other period. In a given month, there might be a few more (or less) births near a full moon than during other parts of the month, but when averaged out over a long period of time, the difference disappears.

You've probably heard that apparently infertile couples who adopt a child frequently go on to give birth to a child. Is there some connection between the two events? To get at the answer to this question, we need comparative data. How, generally, do such couples fare when compared with another group of couples—those who are diagnosed as being infertile but choose not to adopt? (We might also want to look at what happens to fertile couples who do and do not adopt as well.) As it turns out, pregnancy rates for apparently infertile couples who do not adopt are about the same as for similar couples who do adopt.

As these examples suggest, part of the point of making a set of observations is to determine what, if anything, is unusual about the data collected.

Remember, the business of science is understanding. Thus, it is crucial to determine whether a set of observations presents us with something that is not well understood. As we have seen, there is nothing out of the ordinary about the number of births when the moon is full nor about the pregnancy rates of infertile couples; in neither case have we uncovered anything that requires explanation. The process of making observations should always be undertaken with an eye to figuring out whether the results square with what is currently known. And this often involves hunting for the right sort of comparative data—data that will enable us to decide the extent to which our observations have led us to something that really does need explaining.

Have our observations been contaminated by expectation or belief? Our experiences are colored by our beliefs and expectations. When I hear a chirping sound on the ledge outside my office, I assume that what I am hearing is a bird, largely because of prior experiences, the beliefs formulated on the basis of those experiences and other relevant background beliefs. In the past when I have heard chirping outside my window, I have looked out and observed a jay or a robin. And so I make the easy and entirely unproblematic inference that I am now hearing a robin or a jay though, strictly speaking, what I am hearing is only a noise that sounds to me like chirping.

The extent to which beliefs can influence our experiences is powerfully illustrated in the following example. Read the passage below and before reading on, pause and try to figure out what it is about.

> With hocked gems financing him, our hero bravely defied all scornful laughter that tried to prevent his scheme. "Your eyes deceive," he had said. "An egg, not a table correctly typifies this unexplored planet." Now three sturdy sisters sought proof. Forging along, sometimes through calm vastness, yet more often very turbulent peaks and valleys, days became weeks as many doubters spread fearful rumors about the edge. At last from nowhere welcome winged creatures appeared, signifying momentous success.

If you are like me, you found this passage hard to decipher and would find it equally difficult to give a rough paraphrase of what it says. In fact, this story is about Columbus's voyage to the Americas. Reread the passage in light of this new information and note how much sense it makes. Obviously, nothing in the passage has changed. What has altered your experience of reading the passage is a new belief about it.

Normally, we do not need to be too concerned with the influence exerted by expectation and belief over our experience. Many—perhaps most—of our beliefs are well founded and our expectations usually reliable. Nonetheless, it is important to be aware of the extent to which our observations can be influenced by belief and expectation. The point of making a set of scientific observations is to come up with an objective record of what is going on, often in circumstances where we are really not sure. When experience is processed thought the filter of belief and expectation, distortion can creep into our account of what we are observing. Several years ago, for example, some people claimed that the word "sex" could be discerned in a puff of smoke in a brief sequence from the Walt Disney film, *The Lion King*. I have shown the sequence to hundreds of students. Most of those who have not heard that "sex" is in the puff of smoke simply do not see it. However, once they are told what to look for, many people can see the word though many still do not. Seeing is believing, but in this case it seems what one believes can determine what one sees!

Trained scientists are not immune to the influence of expectation and belief on observation. In 1877 and 1881, the Italian astronomer, Giovanni Schiaparelli, turned his telescope to Mars which was unusually close to earth. Schiaparelli claimed that he had observed *canali* on the surface of the planet. Reports of this event in the English speaking media translated the Italian *canali* as "canals" though the word means both "canals" and "channels," the latter meaning being intended by Schiaparelli. Schiaparelli had observed straight lines arranged in a complex fashion but he did not take this to be unequivocal evidence of intelligent beings on Mars. A number of astronomers, among them the American Percival Lowell, claimed also to see Martian "canals," some going so far as to draw detailed maps of them. (At the time, astronomical photography was not sufficiently developed to allow for pictures of Mars. The "canals" were observed visually, a fact that allowed for a good deal of leeway in interpreting what was observed.) Of course, there are not canals on Mars. Those astronomers who believed they were seeing canals were victims of the influence belief can exert over observation.

An even more remarkable example of the extent to which belief can influence scientific observation involves a long since discredited phenomenon, N-rays. Several years after the discovery of X-rays in the late1800s, a highly respected French physicist, René Blondlot, announced that he had detected a subtle new form of radiation, N-rays, named after the University of Nancy, where he was a professor. The evidence for the new form of radiation was provided by changes in the intensity of a spark when jumping a gap between two wires running from a cathode ray tube, the forerunner of the modern TV tube. In subsequent experiments, Blondlot discovered that the effects of N-rays were the most pronounced for very weak and short sparks and that they could be refracted by a prism, something not true of X-rays. The problem was that other experimenters had mixed results in trying to replicate Blondlot's experiments. Some confirmed his findings, others had no luck. One researcher, Auguste Charpentier, claimed to have evidence that N-rays are emitted by people and animals. The main problem faced by researchers was that the effects of N-rays were quite subtle, involving only slight variations in light intensity. Some critics claimed that the effects could be attributed to the way the human eye reacts to faint light sources. Against his critics, Blondlot and his colleagues insisted they had demonstrated the existence of a new form of radiation, even going so far as to suggest that people not properly trained to observe N-rays would have difficulty detecting them. Matters came to a head in 1905 when an American physicist, Robert Wood, came to Nancy to observe Blondlot's work. One crucial experiment was intended to demonstrate the deflection of N-rays by a prism.

Wood asked Blondlot to repeat the experiment but, unbeknownst to Blondlot, removed the prism from the apparatus. Blondlot claimed to obtain the same quantitative measurements of N-ray deflection by the prism even when the prism was missing! Wood published the results of his investigations and within a few years, N-ray research had come to an end. The researchers who for several years provided experimental backing for Blondlot's new phenomena had simply allowed belief and expectation to contaminate their findings.

Belief can also influence our decisions as to what to accept or reject as instances of the phenomena we are observing. The tendency to selectively focus on evidence that supports our beliefs while rejecting disconfirming evidence is called *confirmation bias*. If we suspect, in advance of careful observation, that a claim is true, we may inadvertently overlook data contrary to our belief. The last few times I have been at my local video rental store, I had to wait in line for quite a while to check out my film. Is the store woefully understaffed? Unless I am careful, I run the risk of singling out those past experiences that confirm my suspicion while forgetting about those occasions on which I was promptly served. John Edwards, host of TV's *Crossing Over,* claims to be able to communicate with dead relatives and friends of people in the audience. Occasionally, he will provide an audience member with a piece of information that is startlingly accurate. But the bulk of his messages are either wrong or much too vague to signify much of anything. Anyone who believes that Edwards's "hits" demonstrate his psychic abilities is guilty of confirmation bias.

The cases we have considered in this section suggest that it is always worthwhile to step back from a set of observations and gain some much-needed critical perspective by asking the following. *What am I actually seeing, hearing, etc., and what am I bringing to my observation via the filter of belief and expectation?* Two features common to much scientific observation can play an important role in correcting for the influence of belief and expectation. These are the use of instruments to heighten and supplement the senses and the use of quantitative measures to describe and record observations. Instruments like telescopes, microscopes, and medical imaging devices can provide access to phenomena that could not be observed if we were to rely on our senses alone. But they can serve the additional purpose of providing an objective record of what is actually observed. So, for example, a photographic record of the surface of Mars, something not possible at the time of the "discovery" of the canals led to the final demise of the idea of Martian canals. Simple instruments like the balance scale and the meter stick often enable scientists to provide a quantitative account of their observations. Suppose that the students in one of my classes strike me as being unusually tall. This observation can be put on a more objective footing by the simple expedient of measuring each student and then comparing the results with the measurements of students in other classes. As you are no doubt aware, numbers—mathematics—are often used by scientists. (Indeed, as we will see in Chapter 5, one area of mathematics—the study of probability and statistical inference—is an indispensable tool in the study of causal relationships.) This is because numerical measures permit a more precise description of many sorts of phenomena than would otherwise be possible, as our last example suggests.

QUICK REVIEW 2.1 Questions to Ponder When Making Observations

Do you have a clear sense of what the relevant phenomena are?
Have you found a way to correct for anything that may have been overlooked?
What do you know for sure? What is based on fact and what on conjecture or assumption?
Have you considered any necessary comparative data?
Have your beliefs and expectations influenced your observations?

ANOMALOUS PHENOMENA

Accurate observation is especially crucial in science when the phenomena under investigation appear to be *anomalous*. An anomaly is something, some state of affairs, that does not square with current, received ways of understanding nature. In 1989 two chemists, Martin Fleischmann and Stanley Pons, announced the results of a series of experiments in which they claimed to have produced nuclear fusion at room temperature. This discovery, if true, had the potential to supply limitless quantities of inexpensive, clean energy. But "cold fusion," as this phenomenon came to be called, presented the scientific community with a real anomaly. Nuclear fusion is a well known phenomenon; it is the source of the sun's energy and fusion reactions have been created under laboratory conditions. But for the nuclei of atoms to fuse, temperatures in excess of 10 million degrees are required. One byproduct of fusion is the emission of radiation. Yet Pons and Fleischmann claimed to have observed fusion at considerably lower temperature and claimed also to have detected very little radiation. The number of neutrons—one major source of radiation—they reported seeing was at least a million times too small to account for the fusion energy they claimed to have produced. If Pons and Fleischmann were right, much of what physicists have discovered about the nature of atomic nuclei and the conditions under which nuclei will fuse would have to be revised if not jettisoned altogether.[3]

Anomalous phenomena play a central role in the evolution of scientific ideas. Such phenomena can provide a way of testing the limits of our current understanding of how nature works and can suggest new and fruitful areas for scientific investigation. For example, in a short period of time near the beginning of the 20th century, three totally unexpected discoveries were made: X-rays, radioactivity, and the electron. Each challenged conventional views about the structure and behavior of the atom and led within a few years to a much richer understanding of the basic structure of matter. Similarly, the case discussed in Chapter 1—Semmelweis's discovery of "cadaveric matter"—pointed medical science in the direction of a new way of thinking about disease by introducing the then quite startling notion of microorganisms.

No episode from the history of science illustrates the revolutionary impact of anomalous phenomena more powerfully than the discoveries made by Charles Darwin during a five-year sea voyage in the 1830s. Darwin was appointed naturalist on the H.M.S. Beagle, a British navy survey vessel, for a trip that would circle the world in the southern hemisphere. During the voyage Darwin made numerous observations of the various habitats he visited and collected many zoological and botanical species. While visiting the Cape Verde Islands off the coast of Africa he noted that various species of birds resembled species found on the nearby African continent. Later in the voyage Darwin made a series of careful observations of the species inhabiting the small islands of the Galapagos, off the coast of South America. He noted that each island had its own distinct populations of various animals and birds. Darwin made special note of the varieties of finches that inhabited the islands. In particular, he observed that the beaks of finches found on each island varied slightly from those of other islands. His diary contains detailed sketches of these differences along with an account of the tasks these variations enabled the birds to do given the peculiarities of their environment. Moreover, Darwin was surprised to find that similarities between the species inhabiting the Cape Verde and Galapagos islands were much less striking than those he found between those inhabiting the Cape Verde Islands and Africa. At the time, Darwin did not fully understand the significance of his findings. In a letter written from South America in 1834 Darwin said, "I have not one clear idea about cleavage, lines of upheaval. I have no books which tell me much, and what they do I cannot apply to what I see. In consequence, I draw my own conclusions, and most gloriously ridiculous ones they are." But within five years of his return home Darwin had in place the major pieces of a theory about the gradual development of diversity among living things. (*The Origin of Species*, Darwin's full-blown account of the theory, was not published for another twenty years.) The observations Darwin so painstakingly carried out on his five-year voyage both provided a challenge to the traditional view that all life fits into preestablished, fixed categories, and suggested a revolutionary new mechanism which has since become the cornerstone of the modern biological sciences: evolution by natural selection.

New findings in science need not be as revolutionary as the examples we have considered for them to challenge conventional thinking. Many anomalies suggest the need for small, incremental changes to prevailing theory. A recent article in the science section of my local newspaper tells of the discovery that prehistoric cave paintings in southern France are much older than previously believed. Radiocarbon dating reveals that some of the paintings are about 30,000 years old. Previous estimates had suggested that such paintings were done sometime between 12,000 to 17,000 years ago. This finding suggests that current ideas about when humans developed "fairly sophisticated artistic talents" will need to be revised. Another story from the same day's paper reports on a new genetic analysis of chimpanzees living in three western African communities. Previous studies had suggested that female chimpanzees have frequent sexual liaisons with males from other communities. The new study, which examined the DNA of the female's offspring, revealed that nearly all offspring were fathered by males from within the females' community. At the very least, these new findings suggest that our current understanding of chimpanzee social structures will need to undergo some revision. Small discoveries like these and their attendant anomalies are commonplace in the day-to-day business of doing science, but their importance should not be underestimated. The challenges they pose to prevailing ideas are the clues required if scientific understanding is to expand.

Anomalies are not the exclusive province of science. Many people claim to have witnessed or to be able to do extraordinary things, things which are at odds with conventional scientific thinking. Some people claim to be able to see colorful "auras" emanating from the human body and to be able to discern things about the character of a person by careful study of these "auric emanations." Others claim to have been contacted by extraterrestrials or to have seen alien spacecraft—UFOs—hovering in the night sky. Astrologers claim to be able to predict things about your future based on the position of the planets at the time of your birth. Similar claims are made by people who read palms, tea leaves and tarot cards. Many people claim to have psychic ability of one sort or another: to be able to "see" the future, to read the minds of others and to manipulate objects by sheer mind power. People claim to have seen ghosts, poltergeists, and assorted cryptozoological creatures—everything from bigfoot to the Loch Ness monster. Many claim to have lived past lives and to have left their bodies during near-death encounters. Others claim to have communicated with the spirits of long-dead people.

Many extraordinary claims involve healing and medicine. Some dentists claim we are being poisoned by the mercury in our fillings. Iridologists claim to be able to diagnose illness by examining nothing more than the iris of the human eye. Faith healers claim to be able to cure all sorts of illness and disability by prayer and the laying on of hands. Psychic surgeons claim they can perform operations without the use of anesthetic or surgical instruments.

All of these claims have several things in common. First, all are highly controversial, in the sense that though there is some evidence for the truth of each, the evidence is sketchy at best. Second, all appear to be at odds with some aspect of our current understanding of the natural world even though the claims generally do not emerge from mainstream science. Finally, advocates of such claims are often unaware of the extent to which their beliefs are in disagreement with established scientific theory.

Suppose, for example, someone claims to be able to levitate. This claim is controversial precisely in that though there is actually some evidence for levitation—photographs and the apparently sincere testimony of people who claim to have levitated—the evidence is limited. Moreover, if levitation is possible then our current understanding of how and where gravity operates will have to be revised unless we are prepared to postulate some undiscovered force of sufficient magnitude to counteract gravity.

Or consider the claim, made by many psychics, to be able divine the future. The evidence for such an ability is scant—in most cases a few clear and correct predictions accompanied by lots of vague and downright wrong ones. Yet if it is the case that some people can "see" what has yet to happen, we must rethink our current view about the nature of causation. Common sense, if nothing else, suggests that if A is the cause of B then A must occur before B can occur. Yet if the future can be seen, effects can be established long before their causes come into existence. Thus, if the future can be foretold, something somewhere is wrong with our current view of causation.

OBSERVING ANOMALIES

Special care must be taken in investigating anomalies. Something that strikes us as anomalous is something we do not fully understand and so we may not know precisely what we should be looking for in our initial observations. When, for example, the first cases of what later came to be known as AIDS were reported in the late 70s, medical researchers knew very little about what they were facing. A particular group of people—gay men in the U.S. and Sweden and heterosexuals in Tanzania and Haiti—began showing remarkably similar symptoms. By 1980 a significant number were dying and by 1981 an alarming number of cases of a rare cancer—Kaposi's sarcoma—were appearing in otherwise healthy gay men. Beyond this, little was known. The extent and nature of the epidemic were unclear and no one had a real clue as to what the cause or causes might be. Moreover, the progression of the disease through the populations it affected did not square well with what was believed about the spread of infectious disease. Years of careful observations, many involving factors that turned out to have no bearing on the problem, were required before the first, tentative picture of the extent and nature of the AIDS epidemic began to emerge.

Anomalies are puzzling and unfamiliar and they are potentially revolutionary as well. If an anomaly can be documented, something has to give. Accepted ideas need to be revised and new forms of explanation may need to be developed and tested. Because so much is at stake the investigation of anomalies must be undertaken with two goals in mind. The first, of course, is to uncover the facts, to get a sense of what is going on. The second is to determine whether the phenomena can be "explained away." Can the phenomena be accounted for by reference to familiar, conventional modes of explanation? Only if conventional explanation fails can we be confident we have uncovered something that is genuinely anomalous. When confronted with an apparent anomaly, most scientists will immediately try to deflate the air of mystery surrounding the phenomenon. So, for example, within days of the first reports of cold fusion, many mainstream physicists began to suspect that Pons' and Fleischmann's results could be explained in a way that did not involve nuclear fusion. And as things turned out, they were right. The excess heat energy produced in their experiments was the product of a well-understood chemical, not nuclear, reaction. This sort of response when confronted with an apparent anomaly is not, as is sometimes suggested, the product of an inability on the part of mainstream scientists to cope with anything that challenges orthodox views.

It is, rather, the first necessary step in determining whether something is genuinely anomalous.

In investigating purported anomalies, then, we need to look for clues as to what is going on but also for clues that suggest that the phenomena can be explained within the framework of conventional, established methods of explanation. Several years ago, a resident of Seattle, Washington, commented in a letter to the editor of the city's major daily newspaper that something was causing tiny scratches and pock marks in the windshield of his car. Subsequently a lot of others wrote to the paper confirming that this phenomenon was widespread. Articles and letters appeared that attempted to explain this seeming anomaly. People speculated about everything from acid rain to industrial pollutants to mysterious new chemicals used to de-ice roads in winter. But consider one additional piece of information. The rash of reports of damaged windshields began only after the initial newspaper letter reporting this phenomenon. In light of this new fact, a much simpler explanation comes to mind, one that robs the whole affair of its air of mystery. As it turns out, the effect of the initial letter to the editor was to encourage people to look *at* their windshields, not *through* them. People were actually looking at their windshields closely for the first time and noticing marks and scratches that had accumulated over the years.

Many anomalies involve the sorts of extraordinary claims discussed in the last section. Often such claims derive their air of mystery from missing information, information that may suggest a plausible ordinary explanation. When confronted with such claims it is always a good idea to look for information that has been overlooked by those making the claims. Consider, for example, the strange case of crop circles. In the late 1980s, hundreds of circular and semicircular indentations were discovered in the wheat and corn fields of southern England. There seemed to be no obvious explanation for the origin of these amazing figures. There was no evidence, for example, that people made the circles: many occurred in the middle of crop fields where there were no obvious signs of human intrusion. What was overlooked in just about every story about the circles was the fact that, near every crop circle—and in some cases even running through the circles—were what are called "tramlines." Tramlines are the indentations made by tractors as they travel through the crop fields. One of the most puzzling things about crop circles is said to be the fact that there is no sign of human intrusion. There are no footprints or bent plants leading to the circles. Thus at first glance it may seem unlikely that the circles are hoaxes. Though there are no signs of human intrusion, it is conceivable that a person could simply walk in the tramlines to the point where the circle was to be constructed yet leave no signs of intrusion. Thus, accounts of the crop circles retain much of their sense of mystery only when the facts about tramlines are ignored.[4]

You are probably familiar with some of the strange things that are said to have happened in the Bermuda Triangle, an expanse of several thousand square miles off the coast of southern Florida. Hundreds of boats and planes have mysteriously disappeared in the area over the years. Books about the mysterious happenings in the Bermuda Triangle will typically describe in great detail cases in which it is clearly documented that a boat or plane, known to be traveling in vicinity of the Bermuda Triangle, disappeared, never to be heard from again. Yet two interesting facts are conspicuously missing in most of these reports. In many of the instances described, wreckage is subsequently found, suggesting an accident, not a mysterious disappearance. Moreover, in just about any expanse of ocean of this size near a large population area, like the east coast of Florida, there will be a number of "mysterious" disappearances due to accidents, storms, inexperienced sailors and pilots, etc. Only when these facts are omitted, does the Bermuda Triangle take on the character of a great anomaly.[5]

THE BURDEN OF PROOF

In science, as we have seen, anomalies are regarded with a healthy dose of skepticism.

This attitude may at first seem at odds with the idea of an open, unbiased examination of the facts. But skepticism toward the anomalous is neither narrow-minded nor a knee-jerk defense of the status quo. A vast body of evidence is available suggesting that any given anomalous claim is probably false. Imagine, for example, if someone were to report that they had just seen a man who was at least 10 feet tall. Now this would certainly be anomalous; it is at odds with everything we know about the limits of human growth. Of the nearly limitless number of human beings who have lived on this planet, none has come near to approaching 10 feet in height. What this means is that there is an extraordinarily large body of evidence to suggest that the claim of a 10-foot tall man is false. Thus, lacking very strong evidence for such a claim, skepticism about its truth is only reasonable. The burden of proof, in other words, lies with the person who claims to have observed something anomalous. The more extraordinary the anomalous claim—the more extensive the evidence it is false—the more rigorous must be the evidence required before accepting the claim.

This principle—extraordinary claims require extraordinary evidence—is the basis of the skepticism with which the scientific community generally greets claims of the anomalous. It is the reason why, for example, nuclear physicists were so quickly skeptical of the claims for cold fusion. Years of accumulated experimental evidence made it a near certainty that fusion can occur only at very high temperatures, and these results made perfect sense against the backdrop of the accepted theory of how atomic nuclei interact.

Though anomalous phenomena are regarded with skepticism, scientists will acknowledge the existence of such phenomena—sometimes reluctantly—when provided with unequivocal evidence. In 1986, George Bednorz and Karl Mueller of IBM's Zurich laboratory announced that they had discovered a new class of ceramic materials in which resistance-free electricity can flow at relatively high temperatures. What made this discovery something of an anomaly was the fact that superconductivity, as this phenomenon is called, was thought to be possible only at much lower temperatures. Though this discovery was startling and unexpected, the scientific community was quick to accept it once the evidence was in. Bednorz and Mueller published their results along with a detailed account of the conditions under which the material would conduct electricity with virtually no resistance at high temperatures. Other physicists were quickly able to reproduce their results. With little fanfare, a well-documented anomaly was embraced by the mainstream scientific community. (Bednorz and Mueller were awarded the Nobel Prize for their discovery a year later.)

Extraordinary claims arising from sources outside of mainstream science are also at odds with a large body of contrary evidence, much of which comes from the accumulated findings of science. Here again, the burden of proof lies with advocates of such claims. Suppose a famous psychic were to claim to able to bend keys telekinetically—by simply willing them to bend—and were to give us a demonstration. He holds an ordinary house or car key in one hand, concentrates his thoughts and the key actually seems to bend! But wait a minute. We have seen magicians perform similar feats using simple sleight of hand and misdirection. Unfortunately, our psychic refuses to perform his feat in the presence of a skilled magician on the grounds that he finds it impossible to perform in the presence of people who are skeptical. Some things, claims our psychic, are not meant to be tested.

What are we to make of our psychic's demonstration? Is it a genuine feat of telekinesis or just a bit of sleight of hand? The case for the latter is based on a well-established scientific principle that telekinesis seems to violate. The principle is universal and has been confirmed in countless observations in every field of scientific endeavor. It is that one event cannot influence another without some intervening mechanism or medium. The flow of blood in the human body resists the pull of gravity, in part, because of the pumping action of the heart. Magnets influence the movement of metallic particles via an intervening medium, their surrounding magnetic fields. In fact, there are no known instances of what is sometimes called "action at a distance"—actions or events causally related to antecedent but remote actions or events wherein there is not some intervening medium or mechanism. A variant of this principle seems to hold for human action as well. If I want to bring about a change in the world external to my mind, I must do more than "will" the change to happen. In general it is well established that a person's mind cannot effect a change in the physical world without the intervention of some physical energy or force. If, say, I want to move an object from one spot to another, simply willing the object to move is insufficient to accomplish my purposes. I must figure out some way—some sequence of actions—which will result in the goal I will myself to accomplish.

Now, it may turn out that the "no action at a distance" principle is false. It may be, that is, that we will eventually discover some phenomenon that involves action at a distance. It may even turn out that our psychic will prove to be the exception to the rule. Either that or there is some subtle medium or mechanism at work which has so far eluded our detection, another anomaly.

Thus, because so much is at stake, we are entirely justified in demanding extraordinarily decisive evidence for our psychic's claim to influence objects telekinetically. In the absence of such evidence—evidence of the sort that could be provided by carefully monitored testing in the presence of a skilled magician—we have every reason to doubt our psychic's extraordinary ability. For if our psychic can do what he claims, we must take seriously the notion that forces, processes are at work in nature that have so far escaped our detection; we must begin thinking about revisions to our current understanding of things.