THE NATURE OF SCIENTIFIC INQUIRY

by

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PREFACE TO THE INSTRUCTOR

These materials were developed for a beginning undergraduate course in philosophy of science. In my opinion this textbook has two major strong points. First, there are frequent references to real episodes in science. Secondly, it contains lots of exercises. In my experience even graduate students sometimes have trouble applying philosophical models such as Hempel's theory of explanation to real live cases.

The major weakness of the book is that it provides very little discussion of statistical explanations and the testing of statistical hypotheses. There are two reasons for the emphasis on universal generalizations and deductive explanations. First, many of the central points about scientific method can be made using examples which do not involve statistics. Secondly, there is not time in a one semester course to introduce probability concepts in a meaningful way.
CHAPTER I
A CRITIQUE OF INDUCTIVISM AND RATIONALISM

He flattered himself on being a man without any prejudices; and this pretension itself is a very great prejudice.

--Anatole France

By collecting all facts which bore in any way on the variation of animals and plants under domestication and nature, some light might perhaps be thrown on the whole subject. My first note-book was opened in July 1837. I worked on true Baconian principles, and, without any theory, collected facts on a wholesale scale . . .

--Charles Darwin

It is commonly claimed that whereas the patterns of reasoning in mathematics are deductive (i.e., one draws necessary conclusions from strong, general principles), the arguments which scientists typically use are inductive (one starts with reports about individual observations and tentatively draws general conclusions from them).

We will characterize deductive arguments more carefully in Chapter III. Right now, perhaps, an example will suffice:

The sum of the angles in any triangle equals the sum of two right angles. In any isosceles triangle the base angles are equal. Therefore, the base angle of any isosceles triangle must be less than a right angle.

Note that the conclusion follows necessarily from the premises.

By contrast inductive arguments only make their conclusions more or less plausible. For example:

Dry twigs are flammable.
Dry pine needles are flammable.
Dry sawdust is flammable.
Dry paper is flammable.
Perhaps all dry wood products are flammable. Note that the conclusion doesn't follow with certainty because the premises don't cover all possible cases--dry leaves, dry logs, dry cellulose treated with flame retardant, etc.

When used in a narrow, strict sense, "inductive" only describes the form of an argument--namely, that the conclusion is more general than the premises. However, in popular use it often refers also to the content of the inferences made in science--namely, the fact that they describe observations and experiments.

So when people compare science and mathematics and describe science as being inductive, they are contrasting not only the forms of reasoning used but also the sources of the premises. It is commonly held that the starting points in science come from experience while the first principles in mathematics can be known to be true without relying on experience.

To stress the fact that the inductivist account of science makes claims about the content of science as well as the form of inferences used, I will sometimes speak of the empiricist-inductivist theory of science.

I. General Features of Inductivist Methodology

According to the empiricist-inductivist account, the scientist must begin with an empty mind and collect data through observation. The ideal scientific mind, according to this position, is like an empty bucket waiting to be filled. First of all the scientist must not have any preconceptions or expectations about what he might find. Secondly, he should keep all his senses alert, so as to collect all the information coming in. He must not interpret or filter the data provided by his senses. Neither must he seek out bits of data which he thinks might be particularly relevant, because this would be to introduce a preconception.

The next stage in a scientific investigation is to classify the mass of data collected as above and to note any regularities or correlations between categories. Thus one may note that whenever one sees dancing red flames in the vicinity of one's finger, one feels heat and pain.

After a good deal of data has been collected and classified, one may begin to make cautious generalizations and to extend them to cover unexamined cases. Thus, you might conclude that not only has fire burned you on occasions in the past, but it will continue to do so in the future. However,
one should not make any generalizations about fire burning other people unless one has had some experience in that area.

This approach is called empiricist because it claims that all knowledge comes from the senses (reason is given at most a very minor role -- that of classifying). It is called inductivist because the most important inferences which are used move from individual cases to universal generalizations.

Briefly then, the basic empiricist-inductivist account of scientific method is as follows:

(1) Begin without any preconceptions
(2) Collect data non-selectively
(3) Classify it
(4) Make cautious inductive inferences

As it stands this account is completely impractical. To see why, do the following: Pick up your pen and record your observations without any selection whatsoever during the next minute. (Stop now and do it!)

First of all, if you could succeed in recording everything you would end up with a hopeless mish-mash of items: "toe itches, pen is red, breeze blowing, arm on desk . . ." More than likely though what you ended up with are reports which are patterned according to the focus of your attention: "candle is red, candle is soft, I can scratch it with my fingernail, wax goes under my nail . . ."

Since we always do science with some question or problem in mind, let us explicitly include that in our statement of the method. Our amended empiricist-inductivist account would then go as follows:

(0) Focus on a question.
(1) Begin without any preconceptions as to its answer.
(2) Collect data relevant to the question.
(3) Analyze it.
(4) Make a cautious inductive inference to the answer.

This general method lacks detail. How do we know which data are relevant? We will now turn to two different variants of inductivism.
II. Induction by Association

The simplest variant of the general inductive method discussed above proceeds by collecting data about various circumstances which are positively associated with the phenomenon in question.

Let me explain through an example. Suppose you are afflicted with sporadic episodes of intense sneezing and you are determined to find out what causes it. A proponent of induction-by-association would advise you to proceed as follows:

Every time you sneeze, write down in your notebook all the circumstances associated with it. Since you are looking for the cause of your sneezing, you may limit your inquiry to factors which either preceded or were simultaneous with the sneeze. (Causes never follow their effects.)

Your notebook entries might look as follows:

<table>
<thead>
<tr>
<th>TIME OF SNEEZE</th>
<th>ASSOCIATED (JUST PREVIOUS) CIRCUMSTANCES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sneezed at 10:41 AM</td>
<td>Phone rang, took a breath, clock ticked, reading page of philosophy, canary sang, drank coffee . . .</td>
</tr>
<tr>
<td>Sneezed at 2:39 PM</td>
<td>Holding a pencil, took a breath, studying German, clock ticked, dog yawned . . .</td>
</tr>
</tbody>
</table>

To analyze the list, one searches for a factor which is always present just before you sneeze. Any common factors are candidates for the cause you are looking for. Given the short data table above, possible candidates for the cause of your sneezing are: breathing and hearing a clock ticking (either separately or conjointly). But of course many more observations are required before one is entitled to draw any inductive conclusions.

As the above example shows, one trouble with the method of association is that it may fail to eliminate causally extraneous factors, such as the ticking clock or breathing, which are widely present. It is surely important to add to the above record the additional information that sometimes when the clock ticks you don't sneeze! Negative cases can be just as informative as positive ones! This brings us to the second variant of inductivism.
III. Bacon's Theory of Scientific Method - Induction by Elimination

Perhaps no philosopher has ever advocated the naive approach described above, although some science textbook writers have propounded similar views. Let us now turn to an inductivist methodology which was defended by a philosopher, that described by Francis Bacon in his *Novum Organum* in 1620. (References to this work will give the book number first, followed by the aphorism number.)

Bacon, a contemporary of Galileo (mechanics), Gilbert (magnetism), and Harvey (circulation of the blood) was a judge and essayist. He was convinced that the Aristotelian scientific legacy was sterile. People should purge their minds of old ideas and start afresh. And they should base their new science on a new method.

I will now describe the essential features of Bacon's method, although I will not always use Bacon's own terminology.

According to Bacon, one begins with a "what-is" question, such as, "What is the essential nature of heat?" One then compiles a list of instances of heat. (Bacon calls such lists "histories", using the term as we do when we speak of a Natural History museum.)

Bacon describes this first step as follows:

"... such collection must be made in the manner of a history, without premature speculation, or any great amount of subtlety" (II-11).

So far Bacon sounds very much like a naive inductivist although he does at least allow one to focus on a particular type of phenomena, e.g., heat. However, he goes on to specify that the list should include as wide a variety of instances as possible. His own history of heat includes the following: the rays of the sun, volcanic flames, bodies rubbed violently, damp hay, quicklime sprinkled with water, fresh horse dung, acids (which burn the skin), and hot herbs (which burn the eyes and tongue!).

We can already eliminate certain things as being the essential nature of heat. Since the rays of the sun are hot we know that heat needn't originate from terrestrial bodies. Since stones get hot when rubbed, we know that it needn't have anything to do with live or animate materials. But Bacon considers this method to be incomplete. For example, all of the above
examples of heat have the property of being visible. Yet we hardly want to say that visibility is the essential characteristic of heat! The crucial thing to note, according to Bacon, is that the essential characteristic we are looking for should not only be present when heat is present, but also absent when heat is absent.

Put in modern terminology, if we are looking for a necessary and sufficient condition for heat (call it C), then both of the following conditionals should hold:

1. $H \rightarrow C$ (if heat is present, the condition must be present)
2. $\sim H \rightarrow \sim C$ (if heat is absent, the condition must be absent)

Bacon suggests, therefore, that a second list be drawn up. This new list should describe instances which are as similar as possible to the first instances, except that the phenomenon is absent!

Thus "sun rays" from the list of instances where heat is present is matched with "moon's rays". (Bacon considers the light of the moon to be cold.) This pair of instances shows that light is not always accompanied by heat.

Bacon then asks the scientist to draw up a third list, what he calls a "table of degrees or comparison". Here we collect observations of cases where the amount of heat varies:

"Animals increase in heat by motion and exercise, wine, feasting, venus, burning fevers, and pain."

"... the sun ... gives more heat in perigee ... than in apogee."

"Motion increases heat, as you may see in bellows and by blowing ... ." If the observations one needed were not already available, Bacon suggested that experiments be devised. For example, do thin anvils get hotter than thick anvils when they are struck with a hammer? (II-13)

By judicious use of these three lists, one can eliminate a wide variety of candidates for the essence of heat. Bacon describes the process as follows:

"the first work, therefore, of true induction ... is the rejection or exclusion of the several natures [properties] which are not found in some
instances where the given nature [heat] is present, or are found in some instance where the given nature is absent, or are found to increase in some instance where the given nature decreases, or to decrease when the given nature increases. Then indeed, after the rejection and exclusion has been duly made, there will remain at the bottom, all light opinions vanishing into smoke, a form [essential nature] affirmative, solid, and true and well defined." (II-16)

Although Bacon realizes that one may have to compile enormous histories before the elimination task is complete, he is confident that the task is finite and eventually one will end up with a single property which is the answer we were looking for.

Let us now compare Bacon's approach with the method of induction by association described above by applying to the problem about the cause of sneezing. Bacon agrees with the associationist that the first step is to compile lists of factors which are found when sneezing is found.

But he also directs the investigator to actively seek out cases in which those factors are present but sneezing is absent, so in our example we would need to record cases such as the following:

<table>
<thead>
<tr>
<th>TIME OF NON-SNEEZE</th>
<th>FACTORS PRESENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>11:05 AM - didn't sneeze for 5 minutes.</td>
<td>Breathing, clock ticked, studying German, etc.</td>
</tr>
</tbody>
</table>

This one case enables us to eliminate a whole cluster of candidates. Bacon's method of comparison of degrees doesn't really apply very well to the case of sneezing since the intensity of a sneeze is rather hard to quantify, but we could do studies of the rate of sneezing and factors which varied with it.

EXERCISES A:

1. What would Bacon say about the following? What additional kinds of data should be collected?

(a) I'm starting to think all Englishmen in New York City wear bowler hats! Every time I see someone wearing a bowler hat here in New York City, I go up and say, "Are you English?" and they always say, "Rather, old chap!"
(b) Wishes really do come true! Every time I wish for something real hard and then get it, I put a little flower up on my bulletin board. This one is from passing my calculus mid-term; that one went up when I wished for money and my mom sent some; this new one commemorates my first date with Dreamboat.

(c) Don't tell me Martians aren't promiscuous! I work in the Galactic VD clinic and every damn Martian that comes in here has some wild story to tell about how they got those tell-tale pimples on their elbows.

2. According to Skinner's theory of conditioning, do rats behave as if they use induction by association or induction by elimination? Or neither?

3. The following passage is taken from an allergy doctor's handout to patients. How well does it conform to Bacon's methodology? (Be specific.)

"[The method requires] an accurate and close observation, over a long period of time, of the patient's environment, habits, and diet. The diet can be determined by keeping a diet diary and observing the frequency of any food as it appears in relation to the attack. A modification of this is to systematically eliminate certain suspected allergens from the diet for a trial period of several weeks.

The avoidance of the offending allergen from the patient's environment is the method of treatment that is to be preferred. This method is attempted in many ways. If the allergen is animal hair, the offending animal is eliminated. If it is a food, the food is restricted or eliminated. If it is house dust, an attempt is made to dust-proof the sleeping area and the rest of the house, wherever it is at all possible. In such cases, the amount of relief from symptoms is directly proportionate to the thoroughness with which the allergens are eliminated."
IV. Evaluation of Inductivism

Bacon's theory of eliminative induction is superior to simple induction by association because it stresses the importance of collecting negative instances and looking at a wide variety of cases. Bacon's methodology was quite influential in the early Royal Society. People drew up histories of any number of things. If one were interested in the nature of color, one collected peacock's feathers, mother of pearl, oil slicks and Newton's rings. And since Bacon had stressed the importance of a wide variety of instances, all sorts of exotica, ranging from two-headed calves to unusual plants and animals from the New World were duly stored away.

However, the leaders of the Scientific Revolution (the period centering around Newton—roughly Galileo to Lavoisier) also violated Bacon's methodology and this is quite fortunate, because it still retains some of the marked weaknesses of the general inductivist approach. In the first place, it seems both impossible and unwise to start with an empty mind. It is impossible because we are even born with preconceptions. Baby ducks "think" that any middle-sized object which moves in their vicinity is their mother and start following it around. (This phenomenon is known as "imprinting".) Infants tend to smile at black and white patches which are arranged to depict a face and babies have an innate fear of falling. Of course, these preconceptions may be wrong—ducks may be imprinted on moving footballs, infants may smile at cardboard boxes, and a baby's fear of crawling onto a transparent glass floor is not well-founded.

Since it is impossible to begin any inquiry without preconceptions, the wisest thing to do is to try to expose our preconceptions to criticism and correction. Also, since the set of data which we might sample is potentially infinite it seems wise to use the preconceptions we do have in order to focus our efforts. For example, it might be the case that cancer could be cured by watching Archie Bunker programs with the video tape run backwards. Cancer researchers have a preconception that this is not likely to be the case however, and it seems wise for them not to spend money carrying out this experiment! So contrary to the empiricist-inductivist's advice, it seems that one should not start with a completely open mind; neither should one collect data indiscriminately. Let us now criticize the third step in the suggested process—classification.
According to the inductivist account we should classify our experiences by grouping together things (or experiences) which are similar. Thus we group together cases in which we felt heat and cases in which we saw flame. But the inductivist's notion of similarity is question begging. Since no two experiences are exactly alike we must have some preconceptions as to which sorts of things we ought to count as similar. We need a criterion as to how similar objects or experiences should be before they are grouped together and in which respects they should resemble each other.

For example, how should one classify the following objects:

According to size, shape, shading, position on the page, straight or curved boundary, aesthetic merit, usefulness in building construction, or what have you? I.Q. tests and Sesame Street notwithstanding, direct observation alone in the absence of preconceptions or theories (either inborn or acquired) would not lead us to say that apples and oranges are similar while ravens and writing desks are not.

It is probably the case that, due to our evolutionary history, there are some "natural" classification systems which humans tend to use (although different cultures have quite different color classification schemes). However, we should not use these uncritically, as the naive inductivist approach would suggest. Rather we should design ways of testing the adequacy of our classification systems.

The inductivist theory of method has a noble aim, that of banning prejudice from science and insuring that our scientific conclusions come straight from the facts and are not colored by human biases and misconceptions. The aim is noble, but the method proposed is neither a realistic nor an efficient means of attaining that end.

Scientists must be selective in choosing data to record. (Recall the
When one conducts an experiment, one does not normally record what the experimenter is wearing. (Of course, this factor could be relevant, but one gambles that it isn't.)

Scientists must use language to record the observations which they choose to make. The language used may distort significant similarities or differences. For example, in the sneezing case, a dog was present in one case and a canary in the other. If I had reported both as instances of an animal being in the present, it would immediately point up a basic similarity in the two cases.

There are many other judgments and decisions which a scientist must make. Of course, these choices should be made in as fair-minded and neutral way as possible, but it is impossible to eliminate such decisions as the inductivist tries to do.

There is an additional important problem facing the empiricist-inductivist. Our scientific theories (including the best ones we have) often refer to unobservable objects, such as atoms, genes, intelligence, jealousy. If the mind is supposed to play a passive role in scientific inquiry, serving only as a collating and inferring instrument, how does it happen that we come up with these unobservable notions and furthermore use them successfully to make scientific predictions? It is difficult to imagine how we would ever arrive at theoretical science if we followed the empiricist-inductivist approach described above.

As was intimated in the preface, most scientists and philosophers today would describe the method of science as that of hypothesis testing. Instead of trying to banish all hunches and guesses from their minds, scientists instead try to articulate clear hypotheses and test them as stringently as possible. We will study this theory of method in detail.

EXERCISES B

1. Try to empty your mind completely of all preconceptions. (Pretend you are a Martian.) Compile Baconian tables based on your own experience which are intended to help answer the following question: What causes the phone to ring? Collect five instances for each of Bacon's first two types of tables.
2. How is a raven like a writing desk?

3. Suppose you were studying aggression in a nursery school by observing properties of both the hitter and the hittee and looking for significant differences. Your computerized data sheet has room for only one more entry. Which of the following properties would you choose? and why?

   (a) Cleanliness of child's fingernails
   (b) Number of freckles on child's thumbs
   (c) Child's vocabulary size
   (d) Number of near relatives in prison
   (e) Child's height

4. In the sneeze example I did not record associated events which occurred after the sneeze because we were looking for the cause of sneezing. Would a true inductivist approve of this move? Why, or why not? (How do we know that causes cannot follow effects?)

V. The Rationalist-Deductivist Approach

   All erroneous ideas would perish of their own accord if given clear expression.

   —Vauvenargues

   What is not clear is not French.

   —de Rivarol

   The most powerful cause of error is the war existing between the senses and reason.

   —Pascal

Although we have provided several criticisms of it, you probably found (and perhaps still find) the general features of the empiricist-inductivist approach fairly plausible. Much of Anglo-American philosophy has had a strong empiricist flavor and the popular ideas of our society about science
reflect this. We tend to think that the quality of studies is simply related to the sheer quantity of data available.\(^1\)

The rationalist-deductivist approach (which has been influential on the Continent) would certainly immunize us against this mistake. The empiricist-inductivist advocates first collecting a multiplicity of data and then trying to distill out some general laws by induction. According to the rationalist-deductivist, however, the most important parts of scientific theories are derived from self-evident truths given by reason. The scientist must begin by carefully analyzing his beliefs until he finds some which are clear, distinct and self-evidently true. The concepts and principles which can be discovered through rational (as opposed to empirical) inquiry form the basis of science. Although the details of the operation of the universe may require observation, the most fundamental laws of nature are either given directly to reason or are derivable from the axioms which are self-evidently true. Just as the geometer can tell by reason alone that all points on the circumference of a circle are equidistant from the center, so can the physicist discover the law of the lever just by thinking carefully. No experiments are required and, in fact, they would be misleading since all of the actual levers in the world are subject to friction and are non-ideal.

It may seem very unlikely that one can discover a truth about the world just by reason alone. But let us examine a very plausible sounding derivation of the law of the lever described by Ernst Mach in his history of mechanics:

"Galileo imagines a heavy horizontal prism, homogeneous in material composition, suspended by its extremities from a homogeneous bar of the same length. The bar is provided at its middle point with a suspensory attachment. In this case equilibrium will obtain; this we perceive at once.\(^2\) But in this case is contained every other case. Galileo shows this in the

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\(^1\)Thus TV commentators tended to measure the scientific value of the Apollo 15 mission in terms of the greater number of pounds of rocks brought back over previous flights!

\(^2\)If a homogeneous bar is suspended at its geometrical center, reason alone (so it is claimed) tells us that neither end will drop. Since both sides of the bar are identical what could cause one to behave differently from the other? The situation is perfectly symmetrical.
following manner. Let us suppose the whole length of the bar or the prism to be $2(m + n)$. Cut the prism in two, in such a manner that one portion shall have the length $2m$ and the other the length $2n$. We can effect this without disturbing the equilibrium by previously fastening to the bar by threads, close to the point of proposed section, the inside extremities of the two portions. We may then remove all the threads, if the two portions of the prism be antecedently attached to the bar by their centers. Since the whole length of the bar is $2(m + n)$, the length of each half is $m + n$. The distance of the point of suspension of the right-hand portion of the prism from the point of suspension of the bar is therefore $m$, and that of the left-hand portion $n$. It is thus manifest, that equilibrium will still subsist if any weight of the magnitude $2m$ be suspended at the distance $n$ on the one side and any weight of the magnitude $2n$ be suspended at the distance $m$ on the other. The instinctive elements of our perception of this phenomenon are even more prominently displayed in this form of the deduction than in that of Archimedes."

The reader who does not have rationalist instincts will be suspicious. How can one start with pure conceptual truths which appear to be self-evident and generated by reason alone and somehow arrive at contingent truths which describe the material world? Probably one has smuggled in at least one empiricial assumption, but what is it? In the above case, this will be left as a problem for the reader. (See Mach, *The Science of Mechanics*, for a solution.)

The rationalist does not deny that we get some information (so-called initial conditions) through our senses (for example, the actual value of the distance of a particular weight from the fulcrum). However he claims that the
most general principles of science come from reason. He also stresses the importance of the mind in providing the concepts which shape experience. Even to see a plank laid across a sawhorse as a lever (or as a see-saw, for that matter) requires an active mind. To discover the law of the lever requires even more mental activity.

In brief, then, the rationalist-deductivist account of scientific method is as follows:

1. Purge your mind of all concepts which are not clear and distinct and of all principles which are not self-evidently true.
2. Deduce other self-evident truths from the fundamental ones using logic and/or mathematics.
3. Experience is only necessary in order to discover the parameters or initial conditions which describe particular objects or ensembles of objects.

The rationalist-deductionist has no trouble explaining the existence of theoretical science. We can obviously have clear and distinct ideas of things which we have never experienced. Also this account makes it seem plausible that so much of science should be mathematical. Mathematical notions are among the most clear and distinct.

However, the rationalist-deductivist notion of a self-evident scientific truth leads to severe difficulties. Let us assume for the moment that certain statements such as the axioms of Euclidean geometry can be seen to be true by inspecting them carefully. (In fact, arguing for the consistency of Euclidean geometry is a complicated affair and not at all "self-evident"!) However, if we can ascertain the truth of the claim that three-sided polygons have three interior angles without going to experience it is because such claims are conceptual truths, not descriptive ones. We define point, line, angle, side, etc. in such a way as to insure the truth of geometry. (Who would be surprised to learn that all vixens are foxes, or that all objects with kinetic energy are moving?)

But by the same token, truths which can be discovered or validated by introspection (or "conceptual analysis," as it is sometimes called) cannot be descriptive claims about the world. They cannot play any important role in scientific explanations or predictions.
It is perhaps obvious that once we determine whether a certain animal is a vixen or not we have determined by the same process whether it is a fox. One is probably not tempted to call that claim informative, but the case of geometry is more puzzling. We discover the truth of geometry by reason alone, we have said, but yet geometry is used by surveyors! Isn't it informative, one might ask, to be able to predict what the length of the hypotenuse of a string triangle will be when one has measured only its sides? Isn't this a case where one gets new descriptive information out of a self-evident truth?

The relationship between mathematical geometry and physical geometry is a complex one which was not clearly understood from the time of Euclid until around the turn of this century. (Gauss thought he could test whether Euclidean geometry was correct by surveying the triangles formed by three mountain tops and checking to see if the angles added up to 180°!) Briefly, the situation is this. To use Euclidean geometry, a surveyor must do two things. First, he must give each of the terms in the mathematical theory a physical interpretation. He may coordinate "point" with the position of a stake and "straight line" with a taut chain. Perhaps the "length of a line" will be interpreted as the number of links in the chain.

There is a second important thing he must do and that is to check whether the axioms of Euclidean geometry under this physical interpretation give true descriptions of the world. For example, is it true that the number of links in a chain drawn taut around two stakes is less than the links in a chain which is loosely draped between them? (This is the physical interpretation of "A straight line is the shortest distance between two points." ) Probably yes, but it need not be. (Imagine a chain with a complicated inner mechanism such that the links contract whenever lots of pressure is put on them.)

Of course, we normally cleverly choose our physical interpretations so that the axioms will be true under that interpretation. But in any use of mathematics in science both steps are always in fact being made whether we are aware of them or not.

It was the failure to understand exactly what goes on when we apply mathematics to nature which underlay much of the attractiveness of the rationalist program.
The rationalist was wrong in claiming that we can **test** scientific claims using reason alone--for testing, empirical observations are required. But the rationalist was right to point out that hypotheses **originate** in our minds--they cannot be read off directly from experience.

The rationalist was also correct in stressing the importance of deductive logic for science. As we will see later, the logic of hypothesis testing is deductive. And although the method of conceptual analysis cannot be used to discover important scientific truths, it is a valuable way to clarify scientific claims. But whereas the rationalist delighted in the discovery of conceptual truths (statements which are true by virtue of the meanings of the words involved), scientists today would take it to be a grave criticism of a claim were it shown to be tautologous.

For example, opponents of Darwinian theory often say that the Principle of Survival of the Fittest is empty--by definition, anything which survives must be fit! So, the critics say, collecting examples of evolutionary adaptations is as silly as documenting case after case of round circles and young puppies.

Biologists vehemently deny this allegation. First, they point out that there is much more to Darwinian theory than survival of the fittest. (Even in Darwin's original account there were claims about variation, inheritance, and natural selection. Modern genetics adds claims about Mendelian ratios, rates of genetic change, etc.) But even the simple claim that the fittest survive is not true by definition if we always provide an independent criterion for fitness.

For example, to say simply that black moths survive better than white moths in sooty industrial environments because they are fitter is uninformative. But biologists never stop there. They go on to explain the respect in which the superior moths "fit" their environment--the black coloring makes them less visible against trees and protects them from predators.  

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1 The situation in modern biology is complicated by the fact that biologists often use **fitness** as a technical term defined as relative reproductive rate. The discussion above uses **fit** in the ordinary language sense in which Darwin intended it.
In conclusion then, scientists use the rationalists' method of conceptual analysis, but not for the purpose of discovering the basic principles of science. Rather it is to make sure that their claims are not covert tautologies.

EXERCISES C:

1. Which of the following sentences could be affirmed or denied, on the basis of reason (including language analysis) alone? Which would require experience?
   (a) In a democracy there is always a tyrant.
   (b) Upper-class people have more money than lower-class people.
   (c) Adolf Hitler was a tyrant.
   (d) Upper-class people eat more venison than lower-class people.
   (e) Puppies are young dogs.
   (f) Tadpoles are young frogs.
   (g) If Jones is a juvenile delinquent, then Jones is young.
   (h) Deviants experience social disapproval.
   (i) Deviants are never in the majority.

2. Rationalists often use their approach to criticize other people's theories as well as to establish their own. Comment on each of the following arguments. How persuasive are they? Do they smuggle in empirical assumptions?
   a. Every event has a cause. The magnitude of the cause must be commensurate with the magnitude of the effect. If a body speeds up, something is forcing it to accelerate. Therefore, Force is directly proportional to acceleration.
   b. An effect cannot be greater than its cause. Therefore, it cannot be true that higher organisms evolved from lower ones.
   c. There is no reason why right-handedness is preferable to left-handedness. Nature (or natural selection) does not act gratuitously. Therefore, it is only a cultural convention (like driving on the right side of the road) that most people are right-handed.
VI. Towards a Method of Hypothesis Testing

Both of the extreme approaches to scientific method discussed above are faulty. Neither the senses alone nor reason alone provides an adequate basis for science. And no method (even the one recommended below) guarantees the truth of scientific claims.

The method of hypothesis testing borrows elements from both the inductivist and rationalist approaches. It is very similar (at least on the surface) to the method employed by detectives.

1. One starts with a problem (e.g., who killed Cock Robin? Why do gases expand upon heating?)
2. One proposes a hypothesis which if true would explain all of the available data (e.g., Cock Robin died of an arrow wound / the volume of a gas is directly proportional to the absolute temperature).
3. The source of the hypothesis is not important. It may be suggested by looking at closely associated phenomena. It may impress itself on us as a particularly clear and distinct idea. It may result from the use of analogies, models or metaphors. It may occur to us in a dream!
4. The hypothesis is tested by drawing predictions from it and seeing if they are true (e.g., If the Sparrow killed Cock Robin, there should be a bow around his nest. / If gases expand on heating because their molecules move faster, then their diffusion rates should also increase with temperature.)
5. If the prediction is false, that hypothesis is eliminated. If the prediction is true, the hypothesis gains evidential support; however, we never know for sure that it is true. (Here the parallel with the reasoning of detectives breaks down. In the end, suspects often confess, but Nature never admits it when we discover her secrets.)

We now turn to the logic of testing and the nature of deduction.