Knowledge is power.

CHAPTER 1

The Nature of Scientific Inquiry

INSTRUCTIONAL OBJECTIVES

After studying this chapter, the student will be able to:

1 List five major sources of knowledge and comment on the strengths and weaknesses of each source.

2 Describe the characteristics of the scientific approach.

3 State the assumptions underlying science and the attitudes expected of scientists.

4 Specify the purpose and characteristics of scientific theory in the behavioral sciences.

5 Indicate the limitations involved in the application of the scientific approach in the social sciences.

6 Define educational research and give examples.

Educators are, by necessity, decision makers. Daily they face the task of deciding how to plan learning experiences, teach and guide students, organize a school system, and a myriad other matters. Unlike unskilled workers, who are told what to do and how to do it, professionals must plan for themselves. People assume that professionals have the knowledge and skills necessary to make valid decisions about what to do and how. We generally define knowledge as justified true belief. How are educators to know what is true? How do they acquire reliable information? Although there are other sources of knowledge, such as experience, authority, and tradition, scientific knowledge about the educational process makes the most valuable contribution to decision making in education. Educators can turn to this source for reliable information and suggestions to be used in decision making. This fund of knowledge has been made available to educators by scientific inquiry into educational problems. However, education has not always been influenced by the results of such careful and systematic investigations. In fact, the development of an educational science is at a comparatively early stage

SOURCES OF KNOWLEDGE

Before we further pursue the role of scientific inquiry in education, let us review some of the ways in which human beings throughout history have sought knowledge. The major sources of knowledge can be categorized under five headings: (1) experience, (2) authority, (3) deductive reasoning, (4) inductive reasoning, and (5) the scientific approach.

EXPERIENCE

Experience is a familiar and well-used source of knowledge. After trying several routes from home to work, you learn which route takes the least time or is the most free of traffic or is the most scenic. By personal experience, you can find the answers to many of the questions you face. Much wisdom passed from generation to generation is the result of experience. If people were not able to profit from experience, progress would be severely retarded. In fact, this ability to learn from experience is a prime characteristic of intelligent behavior.

Yet for all its usefulness, experience has limitations as a source of knowledge. How you are affected by an event depends on who you are. Two people will have very different experiences in the same situation. The same forest that is a delightful sanctuary to one person may be a menacing wilderness to another. Two supervisors observing the same classroom at the same time could truthfully compile very different reports if one focused on and reported the things that went right and the other focused on and reported the things that went wrong.

Another shortcoming of experience is that you so frequently need to know things that you as an individual cannot learn by experience. A child turned loose to discover arithmetic alone might figure out how to add but would be unlikely to find an efficient way to compute square roots. A teacher could learn through experience the population of a classroom on a particular day but could not personally count the population of the United States.

AUTHORITY

For things difficult or impossible to know by personal experience, people frequently turn to an *authority;* that is, they seek knowledge from someone who has had experience with the problem or has some other source of expertise. People accept as truth the word of recognized authorities. We go to a physician with health questions or to a stockbroker with questions about investments. To learn the size of the U.S. population, we can turn to reports by the U.S. Bureau of the Census. A student can look up the accepted pronunciation of a word in a dictionary. A superintendent can consult a lawyer about a legal problem at school. A beginning teacher asks an experienced one for suggestions and may try a certain technique for teaching reading because the teacher with experience suggests that it is effective.

Throughout history you can find examples of reliance on authority for knowledge, particularly during the Middle Ages when people preferred ancient scholars, such as Plato and Aristotle, and the early Fathers of the Church as sources of information—even over direct observation or experience. Although authority

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is a very useful source of knowledge, you must always ask, How does authority know? In earlier days, people assumed an authority was correct simply because of the position he or she held, such as king, chief, or high priest. Today, people are reluctant to rely on an individual as an authority merely because of position or rank. They are inclined to accept the assertions of an authority only when that authority is indeed a recognized expert in the area.

Closely related to authority are *custom* and *tradition*, on which people depend for answers to many questions related to professional as well as everyday problems. In other words, people often ask, "How has this been done in the past?" and then use the answer as a guide for action. Custom and tradition have been prominent influences in the school setting, where educators often rely on past practices as a dependable guide. However, an examination of the history of education reveals that many traditions that prevailed for years were later found to be erroneous and had to be rejected. For generations, it was considered good practice to humiliate students who made mistakes with dunce caps and the like. It is wise to appraise custom and tradition carefully before you accept them as reliable sources.

Authority is a quick and easy source of knowledge. However, as a source of knowledge, authority has shortcomings that you must consider. First, authorities can be wrong. People often claim to be experts in a field when they do not really have the knowledge to back up the claim. Second, you may find that authorities disagree among themselves on issues, indicating that their authoritative statements are often more personal opinion than fact.

DEDUCTIVE REASONING

Ancient Greek philosophers made perhaps the first significant contribution to the development of a systematic approach for gaining knowledge. Aristotle and his followers introduced the use of **deductive reasoning,** which can be described as a thinking process in which one proceeds from general to specific knowledge through logical argument. An argument consists of a number of statements standing in relation to one another. The final statement is the conclusion, and the rest, called *premises*, offer supporting evidence. A major kind of deductive reasoning is the syllogism. A syllogism consists of a major premise and a minor premise followed by a conclusion. For example, "All men are mortal" (major premise); "The king is a man" (minor premise); "Therefore, the king is mortal" (conclusion). In deductive reasoning, if the premises are true, the conclusion is necessarily true. Deductive reasoning lets you organize premises into patterns that provide conclusive evidence for a conclusion's validity. Mystery fans will recall that Sherlock Holmes frequently would say, "I deduce …" as he combined previously unconnected facts in such a way as to imply a previously unsuspected conclusion.

Deductive reasoning can answer the question, "How likely is it that a student could pass a 20-item multiple choice test with five options per item by chance alone?" Given the premise that there is a 20 percent chance of getting a single item right and an 80 percent chance of getting it wrong and the premise that these same chances are true for every item, Figure 1.1 shows the probability of getting the following outcomes with three items.

The probability of getting three right is .008. There are three ways to get two right and one wrong, so the probability of two right is (.032)(3) = .096. The probability of getting one right and two wrong is (.128)(3) = .384. There is only one way to get three wrong; the probability of that is .512.

If we extended Figure 1.1 to determine the likelihood of getting a passing 60 percent (12 correct items in a 20-item test), we would find there is approximately one chance in 10,000 of passing. The probability of passing two 20-item tests is $(1/10{,}000)^2$ or one chance in 100 million. The notion that one has a reasonable chance of passing a test through sheer guessing is a myth.

Deductive reasoning has its limitations. To arrive at true conclusions, you must begin with true premises. The conclusion of a syllogism can never exceed the content of the premises. Because deductive conclusions are necessarily elaborations on previously existing knowledge, you cannot conduct scientific inquiry through deductive reasoning alone because it is difficult to establish the universal truth of many statements dealing with scientific phenomena. Deductive reasoning can organize what people already know and can point out new relationships as you proceed from the general to the specific, but it is not sufficient as

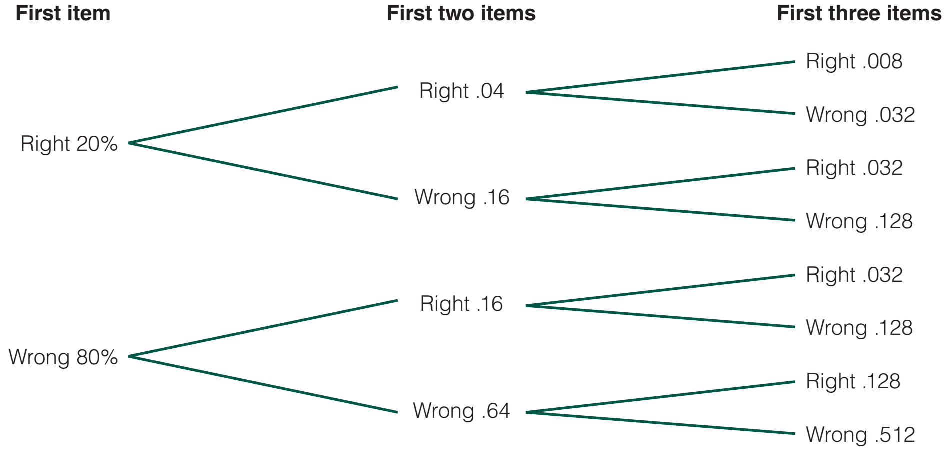

Figure 1.1 Probabilities of Getting Various Outcomes with Three Items

a source of new knowledge. Despite its limitations, deductive reasoning is useful in research because it provides a way to link theory and observation. It lets researchers deduce from existing theory what phenomena they should observe. Deductions from theory can help build hypotheses, which are a vital part of scientific inquiry.

INDUCTIVE REASONING

As noted previously, the conclusions of deductive reasoning are true only if the premises on which they are based are true. But how are you to know if the premises are true? In the Middle Ages, people often substituted dogma for true premises, so they reached invalid conclusions. It was Francis Bacon (1561–1626) who first called for a new approach to knowing. He held that thinkers should not enslave themselves by accepting premises handed down by authority as absolute truth. He believed that an investigator should establish general conclusions on the basis of facts gathered through direct observation. Bacon advised the seeker of truth to observe nature directly and to rid his or her mind of prejudice and preconceived ideas, which Bacon called "idols." For him, obtaining knowledge required that the thinker observe nature itself, gather particular facts, and formulate generalizations from these findings. You can see the importance of observation in the following anecdote (probably apocryphal), attributed to Bacon:

> In the year of our Lord 1432, there arose a grievous quarrel among the brethren over the number of teeth in the mouth of a horse. For 13 days the disputation raged without ceasing. All the ancient books and chronicles were fetched out, and wonderful and ponderous erudition, such as was never before heard of in this region, was made manifest. At the beginning of the 14th day, a youthful friar of goodly bearing asked his learned superiors for permission to add a word, and straightway, to the wonderment of the disputants, whose deep wisdom he sore vexed, he beseeched them to unbend in a manner coarse and unheard-of, and to look in the open mouth of a horse and find an answer to their questionings. At this, their dignity being grievously hurt, they waxed exceedingly wroth; and, joining in a mighty

> uproar, they flew upon him and smote him hip and thigh, and cast him out forthwith. For, said they, surely Satan hath tempted this bold neophyte to declare unholy and unheard-of ways of finding truth contrary to all the teachings of the fathers. After many days more of grievous strife the dove of peace sat on the assembly, and they as one man, declaring the problem to be an everlasting mystery because of a grievous dearth of historical and theological evidence thereof, so ordered the same writ down. (Mees, 1934, p. 115)

The youth in this story was calling for a new way of seeking truth: namely, seeking the facts rather than depending on authority or on sheer speculation. This became the fundamental principle of all science.

In Bacon's system, the investigator made observations on particular events in a class (or category) and then, on the basis of the observed events, made inferences about the whole class. This approach, known as **inductive reasoning**, is the reverse of the deductive method. You can see the difference between deductive and inductive reasoning in the following examples:

Deductive: Every mammal has lungs.
All rabbits are mammals.
Therefore, every rabbit has lungs.

Inductive: Every rabbit that has ever been observed has lungs.
Therefore, every rabbit has lungs.

Note that in deductive reasoning you must know the premises before you can reach a conclusion, but in inductive reasoning you reach a conclusion by observing examples and generalizing from the examples to the whole class or category. To be absolutely certain of an inductive conclusion, the investigator must observe all examples. This is known as **perfect induction** under the Baconian system; it requires that the investigator examine every example of a phenomenon. In the preceding example, to be absolutely sure that every rabbit has lungs, the investigator would have to have observations on all rabbits currently alive, as well as all past and future rabbits. Clearly, this is not feasible; you generally must rely on imperfect induction based on incomplete observation.

Imperfect induction is a system in which you observe a sample of a group and infer from the sample what is characteristic of the entire group. An example of a conclusion based on imperfect induction is the present thinking concerning the physical characteristics of very intelligent children. For many years, people generally believed that exceptionally bright children tended to be poor physical specimens. Even today, cartoonists usually portray the bright child as a scrawny creature with thick spectacles. Terman, a pioneer in the field of mental testing, was interested in the characteristics of exceptionally bright youngsters (Terman, 1926). In a landmark investigation, Terman intensively studied more than 1000 California children who scored higher than 140 on the Stanford–Binet intelligence test. He found the average height, weight, and general physical health of these children to be slightly above average for children of their age. From this and subsequent studies of the phenomenon, researchers have concluded that bright children, far from being scrawny, are slightly more likely to be above average in physical development than children with average IQ scores. Note that this conclusion has not been positively proved. It is simply highly probable. To be positively sure about this conclusion, you would need physical measures for *all* children with IQ scores of 140 or higher on the Stanford–Binet. Even then, you could only be positive about the characteristics of such children today and could not be 100 percent sure that the same would be true of such children in the future. Although imperfect induction does not lead to infallible conclusions, it can provide reliable information about what is likely to be true and on which you can make reasonable decisions.

An inductive way to investigate the question, "Should you stick with your original answers on a multiple-choice test, or should you change your answers when, upon reconsideration, you think you have a better answer?" would be to go over scored exams and identify items with erasures or cross-outs. Then count the changes that go from right to wrong, wrong to right, or wrong to wrong.

Dozens of researchers have published the results of such studies, beginning with Crawford (1928). These studies have all found that more changes are from wrong to right than from right to wrong. Waddell and Blankenship (1994), through a thorough search of the literature for the years 1988–1992, found 61 studies whose results could be combined through meta-analysis (see Chapter 6). The combined results were as follows: 57 percent of changes were from wrong to right, 21 percent were from right to wrong, and 22 percent were from wrong to wrong. Therefore, the best advice is to encourage students to make changes whenever, after rethinking, they find an answer that they prefer over their original one. It is interesting to note that those studies that also asked students and professors their advice found the majority advised sticking with your original answer. The myth that you should stick with your original answer has persisted for generations, despite overwhelming evidence to the contrary.

> It's not so much what folks don't know that causes problems.
> It's what they know that ain't so.
>
> Artemus Ward

THE SCIENTIFIC APPROACH

Exclusive use of induction often resulted in the accumulation of isolated knowledge and information that made little contribution to the advancement of knowledge. Furthermore, people found that many problems could not be solved by induction alone. In the 19th century, scholars began to integrate the most important aspects of the inductive and deductive methods into a new technique, namely the inductive–deductive method, or the **scientific approach.** This approach differs from inductive reasoning in that it uses hypotheses. A **hypothesis** is a statement describing relationships among variables that is tentatively assumed to be true. It identifies observations to be made to investigate a question.

For example, a researcher interested in increasing student on-task behavior might hypothesize that positive teacher feedback increases on-task behavior. All hypotheses indicate specific phenomena to be observed (the variables), in this case positive teacher feedback and on-task behavior.

Charles Darwin, in developing his theory of evolution, is generally recognized as the first to apply this method in the pursuit of knowledge. Darwin reported that he spent a long time making biological observations, hoping to establish some generalizations concerning evolution. In the following passage, he describes how he arrived at a new approach:

> My first note-book (on evolution) was opened in July 1837. I worked on true Baconian principles, and without any theory collected facts on a wholesale scale, more especially with respect to domesticated productions, by printed enquiries, by conversation with skillful breeders and gardeners, and by extensive reading. When I see the list of books of all kinds which I read and abstracted, including whole series of Journals and Transactions, I am surprised at my industry. I soon perceived that selection was the keystone of man's success in making useful races of animals and plants. But how selection would be applied to organisms living in a state of nature remained for some time a mystery to me. In October 1838, that is, fifteen months after I had begun my systematic enquiry, I happened to read for amusement "Malthus on Population," and being well prepared to appreciate the struggle for existence which everywhere goes on from long-continued observation of the habits of animals and plants, it at once struck me that under these circumstances favourable variations would tend to be preserved, and unfavourable ones to be destroyed. The result of this would be the formation of new species. Here then I had at last got a theory by which to work. (Darwin, 2007, p. 68)

Darwin's procedure, involving only observation, was unproductive until reading and further thought led him to formulate a tentative hypothesis to explain the facts that he had gathered through observation. He then proceeded to test this hypothesis by making deductions from it and gathering additional data to determine whether these data would support the hypothesis. From this method of inquiry, Darwin was able to develop his theory of evolution. This use of both inductive and deductive reasoning is characteristic of modern scientific inquiry.

The scientific approach is generally described as a method of acquiring knowledge in which investigators move inductively from their observations to hypotheses and then deductively from the hypotheses to the logical implications of the hypotheses. They deduce the consequences that would follow if a hypothesized relationship were valid. If the deduced implications are compatible with the organized body of accepted knowledge, researchers then further test them by gathering empirical data. On the basis of the evidence, they accept or reject the hypotheses.

The use of hypotheses is the principal difference between the scientific approach and inductive reasoning. In inductive reasoning, you make observations first and then organize the information gained. In the scientific approach, you reason what you would find if a hypothesis were true and then you make systematic observations to confirm (or fail to confirm) the hypothesis.

AN EXAMPLE OF THE SCIENTIFIC APPROACH

In a classic example, award-winning author Robert Pirsig provides a vivid and succinct description of the scientific approach by comparing it to the process of maintaining a motorcycle in good working order:

> Two kinds of logic are used, inductive and deductive. Inductive inferences start with observations of the machine and arrive at general conclusions. For example, if the cycle goes over a bump and the engine misfires, and then goes over another

bump and the engine misfires, and then goes over another bump and the engine misfires, and then goes over a long smooth stretch of road and there is no misfiring, and then goes over a fourth bump and the engine misfires again, one can logically conclude that the misfiring is caused by the bumps. That is induction: reasoning from particular experiences to general truths.

Deductive inferences do the reverse. They start with general knowledge and predict a specific observation. For example, if, from reading the hierarchy of facts about the machine, the mechanic knows the horn of the cycle is powered exclusively by electricity from the battery, then he can logically infer that if the battery is dead the horn will not work. That is deduction.

Solution of problems too complicated for common sense to solve is achieved by long strings of mixed inductive and deductive inferences that weave back and forth between the observed machine and the mental hierarchy of the machine found in the manuals. The correct program for this interweaving is formalized as scientific method.

Actually I've never seen a cycle-maintenance problem complex enough really to require full-scale formal scientific method. Repair problems are not that hard. When I think of formal scientific method an image sometimes comes to mind of an enormous juggernaut, a huge bulldozer—slow, tedious, lumbering, laborious, but invincible. It takes twice as long, five times as long, maybe a dozen times as long as informal mechanic's techniques, but you know in the end you're going to *get* it. There's no fault isolation problem in motorcycle maintenance that can stand up to it. When you've hit a really tough one, tried everything, racked your brain and nothing works, and you know that this time Nature has really decided to be difficult, you say, "Okay, Nature, that's the end of the nice guy," and you crank up the formal scientific method.

For this you keep a lab notebook. Everything gets written down, formally, so that you know at all times where you are, where you've been, where you're going, and where you want to get. In scientific work and electronics technology this is necessary because otherwise the problems get so complex you get lost in them and confused and forget what you know and what you don't know and have to give up. In cycle maintenance things are not that involved, but when confusion starts it's a good idea to hold it down by making everything formal and exact. Sometimes just the act of writing down the problems straightens out your head as to what they really are.

The logical statements entered into the notebook are broken down into six categories: (1) statement of the problem, (2) hypotheses as to the cause of the problem, (3) experiments designed to test each hypothesis, (4) predicted results of the experiments, (5) observed results of the experiments, and (6) conclusions from the results of the experiments. This is not different from the formal arrangement of many college and high school lab notebooks but the purpose here is no longer just busywork. The purpose now is precise guidance of thoughts that will fail if they are not accurate.

The real purpose of scientific method is to make sure Nature hasn't misled you into thinking you know something you don't actually know. There's not a mechanic or scientist or technician alive who hasn't suffered from that one so much that he's not instinctively on guard. That's the main reason why so much scientific and mechanical information sounds so dull and so cautious. If you get careless or go romanticizing scientific information, giving it a flourish here and there, Nature will soon make a complete fool out of you. It does it often enough anyway even when you don't give it opportunities. One must be extremely careful and rigidly logical when dealing with Nature: one logical slip and an entire scientific edifice comes tumbling down. One false deduction about the machine and you can get hung up indefinitely.

In Part One of formal scientific method, which is the statement of the problem, the main skill is in stating absolutely no more than you are positive you know. It is much better to enter a statement "Solve Problem: Why doesn't cycle work?" which sounds dumb but is correct, than it is to enter a statement "Solve Problem: What is wrong with the electrical system?" when you don't absolutely know the trouble is in the electrical system. What you should state is "Solve Problem: What is wrong with cycle?" and then state as the first entry of Part Two: "Hypothesis Number One: The trouble is in the electrical system." You think of as many hypotheses as you can, then you design experiments to test them to see which are true and which are false.

This careful approach to the beginning questions keeps you from taking a major wrong turn which might cause you weeks of extra work or can even hang you up completely. Scientific questions often have a surface appearance of dumbness for this reason. They are asked in order to prevent dumb mistakes later on.

Part Three, that part of formal scientific method called experimentation, is sometimes thought of by romantics as all of science itself because that's the only part with much visual surface. They see lots of test tubes and bizarre equipment and people running around making discoveries. They do not see the experiment as part of a larger intellectual process and so they often confuse experiments with demonstrations, which look the same. A man conducting a gee-whiz science show with fifty thousand dollars' worth of Frankenstein equipment is not doing anything scientific if he knows beforehand what the results of his efforts are going to be. A motorcycle mechanic, on the other hand, who honks the horn to see if the battery works is informally conducting a true scientific experiment. He is testing a hypothesis by putting the question to Nature. The TV scientist who mutters sadly, "The experiment is a failure; we have failed to achieve what we had hoped for," is suffering mainly from a bad scriptwriter. An experiment is never a failure solely because it fails to achieve predicted results. An experiment is a failure only when it also fails adequately to test the hypothesis in question, when the data it produces don't prove anything one way or another.

Skill at this point consists of using experiments that test only the hypothesis in question, nothing less, nothing more. If the horn honks, and the mechanic concludes that the whole electrical system is working, he is in deep trouble. He has reached an illogical conclusion. The honking horn only tells him that the battery and horn are working. To design an experiment properly he has to think very rigidly in terms of what directly causes what. This you know from the hierarchy.

The horn doesn't make the cycle go. Neither does the battery, except in a very indirect way. The point at which the electrical system directly causes the engine to fire is at the spark plugs, and if you don't test here, at the output of the electrical system, you will never really know whether the failure is electrical or not.

To test properly, the mechanic removes the plug and lays it against the engine so that the base around the plug is electrically grounded, kicks the starter lever, and watches the spark-plug gap for a blue spark. If there isn't any he can conclude one of two things: (a) There is an electrical failure or (b) his experiment is sloppy. If he is experienced he will try it a few more times, checking connections, trying every way he can think of to get that plug to fire. Then, if he can't get it to fire, he finally concludes that *a* is correct, there's an electrical failure, and the experiment is over. He has proved that his hypothesis is correct.

In the final category, conclusions, skill comes in stating no more than the experiment has proved. It hasn't proved that when he fixes the electrical system the motorcycle will start. There may be other things wrong. But he does know that the motorcycle isn't going to run until the electrical system is working and he sets up the next formal question: "Solve Problem: What is wrong with the electrical system?" He then sets up hypotheses for these and tests them. By asking the right questions and choosing the right tests and drawing the right conclusions the mechanic works his way down the echelons of the motorcycle hierarchy until he has found the exact specific cause or causes of the engine failure, and then he changes them so that they no longer cause the failure.

An untrained observer will see only physical labor and often get the idea that physical labor is mainly what the mechanic does. Actually the physical labor is the smallest and easiest part of what the mechanic does. By far the greatest part of his work is careful observation and precise thinking. That is why mechanics sometimes seem so taciturn and withdrawn when performing tests. They don't like it when you talk to them because they are concentrating on mental images, hierarchies, and not really looking at you or the physical motorcycle at all. They are using the experiment as part of a program to expand their hierarchy of knowledge of the faulty motorcycle and compare it to the correct hierarchy in their mind. They are looking at underlying form.

—From *Zen and the Art of Motorcycle Maintenance* by Robert M. Pirsig, pp. 107–111.

In Pirsig's narrative, we see five steps that are typical in scientific inquiry:

1. *Identification of the problem*. The first step is the realization that a problem exists. The problem may involve a question about something, a discrepancy in findings, or a gap in knowledge. In Pirsig's example, the fact that the motorcycle did not start constituted the problem.
2. *Statement of the problem*. The next step is the clarification of the problem. The investigator states more precisely the nature and scope of the problem that has been identified.
3. *Formulation of hypotheses*. The investigator formulates hypotheses about possible solutions of the problem. In the example, the first hypothesis was that the motorcycle did not start because of trouble in the electrical system.
4. *Prediction of consequences*. The investigator next predicts the consequences of each hypothesis; that is, what should result if the data support the hypothesis.
5. *Testing of hypotheses*. The researcher gathers objective data to evaluate the adequacy of each hypothesis formulated. If the data support the hypothesis, it is accepted as a reasonable explanation. If the data do not support the hypothesis, it is rejected.

Gribbin (1999) summed up the scientific process with the following quote from Richard Feynman, one of the great physicists of the 20th century:

> In general we look for a new law by the following process. First we guess it. Then we compute the consequences of the guess to see what would be implied if this law that we guessed is right. Then we compare the result of the computation to nature, with experiment or experience, compare it directly with observation, to see if it works. If it disagrees with experiment it is wrong. In that simple statement is the key to science. It does not make any difference how beautiful your guess is. It does not make any difference how smart you are, who made the guess, or what his name is—if it disagrees with experiment it is wrong. (p. 4)

OTHER ASPECTS OF SCIENCE

In addition to the method scientists follow as they seek reliable knowledge, there are certain other aspects of the scientific approach, which we examine briefly. These are (1) assumptions made by scientists, (2) attitudes expected of scientists, and (3) formulation of scientific theory.

ASSUMPTIONS MADE BY SCIENTISTS

A fundamental assumption scientists make is that the events they investigate are lawful or ordered—no event is capricious. Science is based on the belief that all natural phenomena have antecedent factors. This assumption is sometimes referred to as **universal determinism.** Primitive people proposed supernatural causes for most of the events they observed. Modern science did not develop until people began to look beyond supernatural explanations and to depend on the observation of nature itself to provide answers.

This assumption underlies any statement that declares that under specified conditions certain events will occur. For example, the chemist can state that when a mixture of potassium chlorate and manganese dioxide is heated, the process will produce oxygen. Behavioral scientists likewise assume that the behavior of organisms is lawful and predictable. Related to this first assumption is the belief that the events in nature are, at least to a degree, orderly and regular and that people can discover this order and regularity of nature through the scientific method.

A second assumption is that reliable knowledge can ultimately derive only from direct and objective observation. Reliance on empirical observation differentiates science from nonscience. The scientist does not depend on authority or tradition as sources of knowledge but insists on studying empirical evidence. In the history of science we find many examples of scientists who rejected the prevailing notions of their day and proceeded with their observations and experimentation. Galileo's early experiments with falling bodies, which may mark the beginning of modern scientific inquiry, resulted in new knowledge that contradicted notions held by the authorities of his day. A corollary of this assumption is the belief that only phenomena that are subject to observation lie within the realm of scientific investigation.

THINK ABOUT IT 1.1

Match the term on the left with the definition on the right.

1. Universal determinism	a. Proceeding from general to specific knowledge through logical argument
2. Inductive reasoning	b. Deriving general conclusions through direct observation
3. Deductive reasoning	c. A statement describing relationships among variables that is tentatively assumed to be true
4. Hypothesis	d. The assumption that all natural phenomenal have antecedent factors

Answers

1. d; 2. b; 3. a; 4. c

ATTITUDES EXPECTED OF SCIENTISTS

Scientists recognize certain characteristic attitudes that they acquire as they pursue their work:

1. *Scientists are essentially doubters, who maintain a highly skeptical attitude toward the data of science*. Scientists investigate questions concerning the relationships among natural phenomena. Their findings are regarded as tentative, however, and are not accepted by themselves or other scientists unless further investigations can verify them. Verification occurs when repeated observations yield the same or similar results. Verification thus requires scientists to make their research measurements and procedures known so that others may replicate the study and verify, or fail to verify, the findings.
2. *Scientists are objective and impartial*. In conducting observations and interpreting data, scientists seek knowledge and are not trying to prove a point. They take particular care to collect data in such a way that any personal biases they may have will not influence their observations. They look for observable evidence and accept the findings even when those results are contrary to their own opinions. If the accumulated evidence upsets a favorite theory, then they either discard that theory or modify it to agree with the findings.

   In reality, scientists are human like the rest of us. Some scientists have been known to report only findings that agreed with their preconceived ideas or have even made up data to support their contentions. A notorious example occurred when Stalin ruled the Soviet Union. His secretary of agriculture, Lysenko, asserted that environment changed heredity. Those scientists who reported results supporting this contention got published, got to keep their jobs, and got promoted. Those who reported research results contrary to Lysenko's belief often lost their jobs or were sent to Siberia.

   Scientists in other countries tried to replicate these studies, but none of them got results that supported Lysenko's contention. They concluded that the phenomenon did not exist. Soon after Stalin's death, Lysenko's contentions were repudiated, and Soviet scientists admitted that they had reported what was wanted, not what they had observed.

3. *Scientists deal with facts, not values*. Scientists do not indicate any potential moral implications of their findings; they do not make decisions for other people about what is good or what is bad. Scientists provide data concerning the relationships among events, but you must go beyond scientific data if you want a decision about whether a certain consequence is desirable. Thus, although the findings of science may be of key importance in solving a problem about a value decision, the data themselves do not furnish that value judgment.
4. *Scientists are not satisfied with isolated facts but seek to integrate and systematize their findings*. They want to put the things known into an orderly system. Thus, scientists aim for theories that seek to bring together empirical findings into a meaningful pattern. However, they regard these theories as tentative or provisional, subject to revision as new evidence appears.

FORMULATION OF SCIENTIFIC THEORY

The last aspect of the scientific approach we consider here is the construction of theory. The ultimate goal of science is theory formation. Scientists, through empirical investigation, gather many facts, but facts by themselves are of limited usefulness. As facts accumulate, scientists must integrate, organize, and classify to make the isolated findings meaningful. They must identify and explain significant relationships in the data. That is where theory comes into play. Scientists formulate theories to summarize and order the existing knowledge in a particular area. A **theory** may be defined as a set of interrelated constructs and propositions that presents an explanation of phenomena and makes predictions about relationships among variables relevant to the phenomena.

Theories knit together the results of observations, enabling scientists to make general statements about variables and the relationships among variables. Theories range from a few simple generalizations to complex formulations of laws. For example, you can observe that if you hold pressure constant, hydrogen gas expands when its temperature increases from 208°C to 408°C. You can observe that if you hold pressure constant, oxygen gas contracts when its temperature decreases from 608°C to 508°C. A familiar theory, Charles's Law, summarizes the observed effects of temperature changes on the volumes of all gases: When pressure is held constant, as the temperature of a gas increases, its volume increases; and as the temperature of a gas decreases, its volume decreases. The theory not only summarizes previous information but also predicts other phenomena by telling you what to expect of any gas under any temperature change.

Purposes of Theories

Theories serve useful functions in the development of science. They (1) organize empirical findings and explain phenomena, (2) predict phenomena, and (3) stimulate new research. A theory organizes the findings from many separate observations and investigations into a framework that provides explanations of phenomena. We would not have progress if science were composed only of multiple separate facts. A single theory can integrate many facts by showing what variables are related and how they are related. A theory of learning, for example, might explain the relationships among the speed and efficiency of learning and such variables as motivation, reinforcement, practice, and so on. Researchers have developed useful theories to explain motivation, intellectual and cognitive development, moral development, social development, and so on. From the explanatory framework of a theory, scientists can proceed to make predictions about what will happen in novel situations. If these predictions are supported by scientific investigation, then science proceeds finally to control. As soon as a statement (theory) was made about the relationship between the *Anopheles* mosquito and malaria in humans, scientists could (1) *explain* why malaria was endemic in some areas and not in others, (2) *predict* how changes in the environment would entail changes in the incidence of malaria, and (3) *control* malaria by changing the environment.

Researchers state and test hypotheses deduced from theories, which results in the development of new knowledge. Deductions from a theory permit predictions of phenomena, some as yet unobserved. For example, astronomers predicted the existence of the outermost planets from theory long before they were actually observed. Testing the deductions from a theory serves to confirm and elaborate the theory. If, however, research findings do not support the theory, scientists revise it and then collect more data to test the revised theory.

Criteria for Theories

To serve its purpose in science, a theory should satisfy certain criteria. The following are some of the characteristics of a sound theory:

1. *A theory should be able to explain the observed facts relating to a particular problem*. It should be able to propose the "how" and "why" concerning the phenomena under consideration. This explanation of the events should take the simplest form possible. Scientists favor a theory that has fewer complexities and assumptions over a more complicated one. This rule is called the **principle of parsimony**.
2. *A theory should be consistent with observed facts and with the already established body of knowledge*. Scientists build on what has already been found. They look for the theory that provides the most probable or the most efficient way of accounting for the accumulated facts.
3. *A theory should provide means for its verification*. Scientists achieve this for most theories by making deductions in the form of hypotheses stating the consequences that you can expect to observe if the theory is valid. Scientists can then investigate or test these hypotheses empirically to determine whether the data support the theory. We must emphasize that it is inappropriate to speak of the "truth" or "falsity" of a theory. The acceptance or rejection of a theory depends primarily on its *utility*, or usefulness. A theory is useful or not useful depending on how efficiently it leads to predictions concerning observable consequences, which are then confirmed when the empirical data are collected. Even then, any theory is tentative and subject to revision as new evidence accumulates.

   You may recall the old theory of formal discipline, which stated that the mind is like a muscle that can be strengthened through exercise. Subjects such as logic, Latin, and Greek were once included in the curriculum because educators believed them to be best for strengthening the mind. This theory of formal discipline prevailed until the early 20th century, when E. L. Thorndike, William James, and Charles Judd challenged and abandoned it.

4. *A theory should stimulate new discoveries and indicate further areas in need of investigation.*

The goal of theory formation has been achieved to a far greater extent in the physical sciences than in the social sciences, which is not surprising because they are older sciences. In the early days of a science, the emphasis typically is on empiricism; scientists are concerned with collecting facts in particular areas. Only with maturity does a science begin to integrate the isolated knowledge into a theoretical framework.

Although there are marked differences in the number and power of the theories that have been established in the physical and social sciences, theory has the same role to play in the progress of any science. Regardless of the subject matter, theory works in essentially the same way. It serves to summarize existing knowledge, to explain observed events and relationships, and to predict the occurrence of unobserved events and relationships. Theories represent the best efforts to understand the basic structure of the world in which we live.

THINK ABOUT IT 1.2

Throughout history, mankind has sought to explain the source of the sun's heat. The following are among the proposed explanations:

a. The sun is a god miraculously creating heat.
b. The heat comes from combustion like a log burning in a fireplace.
c. The sun is an enormous ball of gas. The pressure created by gravity on this great mass creates great heat.
d. The sun's heat comes from atomic fusion as in the hydrogen bomb.

Questions

1. Which of the explanations are subject to disproof through observation?
2. Which are scientific theories?
3. Most scientific textbooks in the 19th century gave answer *c* as the best explanation of the sun's heat. Later, it was shown that if *c* was true, the sun could only produce heat for a short period of time. Should the publishers of these textbooks apologize for publishing *c* because it has now been shown to be inadequate for explaining the phenomenon?
4. Current texts present answer *d* as the best explanation of the sun's heat. Have we finally reached the correct explanation?

Answers

1. b, c, d
2. b, c, d
3. No. Science is dynamic, never claiming that a theory is the ultimate truth. There is no shame in embracing a theory and then discarding it when a better explanation comes along.
4. We do not know. Currently, it fits the facts. It may be the ultimate answer, but scientists remain open to the possibility that future research may produce a better explanation.

LIMITATIONS OF THE SCIENTIFIC APPROACH IN THE SOCIAL SCIENCES

Despite their use of the scientific approach and accumulation of a large quantity of reliable knowledge, education and the other social sciences have not attained the scientific status typical of the natural sciences. The social sciences have not established generalizations equivalent to the theories of the natural sciences in scope of explanatory power or in capacity to yield precise predictions. Frequently, researchers in the social sciences disagree on what the established facts are or what explanations are satisfactory for the assumed facts. Perhaps the social sciences will never realize the objectives of science as completely as the natural sciences. Certainly, we must stress that using the scientific approach is not in itself a sufficient condition for scientific achievement. Several limitations hinder the application of the scientific approach in education and the other social sciences.

Complexity of Subject Matter

A major obstacle is the inherent complexity of subject matter in the social sciences. Natural scientists deal with physical and biological phenomena. A limited number of variables that can be measured precisely are involved in explaining many of these phenomena, and it is possible to establish universal laws. For example, Boyle's law, summarizing the influence of pressure on gas volume, a law that deals with relatively uncomplicated variables, formulates relations among phenomena that are apparently unvarying throughout the universe.

In contrast, social scientists deal with the human subject. They are concerned with the subject's behavior and development, both as an individual and as a member of a group. They must consider many variables, acting independently and in interaction, in any attempt to understand complex human behavior. Each individual is unique in the way he or she develops, in mental ability, in social and emotional behavior, and in total personality. The behavior of humans in groups and the influence of the behavior of group members on an individual must also be dealt with by social scientists. A group of first-graders in one situation will not behave like first-graders in another situation. There are learners, teachers, and environments, each with variations that contribute to the behavioral phenomena observed in a setting. Thus, researchers must be extremely cautious about making generalizations because the data from one group or in one situation may have limited validity for other groups and other settings.

Difficulties in Observation

Observation, the sine qua non of science, is more difficult in the social sciences than in the natural sciences. Observation in the social sciences is often less objective because it more frequently involves interpretation on the part of the observers. For example, the subject matter for investigation is often a person's responses to the behavior of others. Motives, values, and attitudes are not open to inspection. Observers must make subjective interpretations when they decide that behaviors observed indicate the presence of any particular motive, value, or attitude. The problem is that the personal values and attitudes of social scientists may influence both what they choose to observe and their assessment of the findings on which they base their conclusions. Natural scientists study phenomena that require less subjective interpretation.

Difficulties in Replication

The chemist can objectively observe the reaction between two chemicals in a test tube. The findings can be reported and the observations can be easily replicated by others. Replication is much more difficult to achieve in the social sciences. An American educator cannot reproduce the conditions of a Russian educator's experimental teaching method with the same precision as that with which an American chemist can replicate a Russian chemist's experiment. Even within a single school building, one cannot reproduce a given situation in its entirety and with precision. Social phenomena are singular events and cannot be totally repeated for purposes of observations.

Interaction of Observer and Subjects

An additional problem is that mere observation of social phenomena may produce changes that might not have occurred otherwise. Researchers may think that *X* is causing *Y*, when in fact their own observation of *X* may cause *Y*. For example, in the well-known Hawthorne experiments, changes in worker productivity stemmed not from the varying working conditions but from the mere fact that the workers knew they had been singled out for investigation. Investigators are human beings, and their presence as observers in a situation may change the behavior of their human subjects. The use of hidden video cameras and audio cassettes may help minimize this interaction in some cases, but much social science research includes the responses of human subjects to human observers.

Difficulties in Control

The range of possibilities for controlled experiments on human subjects is much more limited than in the natural sciences. The complexities involved in research on human subjects present control problems that have no parallels in the natural sciences. In the latter, rigid control of experimental conditions is possible in the laboratory. Such control is not possible with human subjects; social scientists must deal with many variables simultaneously and must work under conditions that are much less precise. They try to identify and control as many of these variables as possible, but the task is sometimes very difficult.

Problems of Measurement

Systematic research must provide for measurement of the variables involved. The tools for measurement in the social sciences are much less perfect and precise than the tools of the natural sciences. Social science has nothing that can compare with the precision of the ruler, the thermometer, or numerous laboratory instruments. We have already pointed out that an understanding of human behavior is complicated by the large number of determining variables acting independently and in interaction. The multivariate statistical devices available for analyzing data in the social sciences take care of relatively few of the factors that obviously are interacting. Furthermore, these devices permit you to attribute the variance only to factors operating at the time of measurement. Factors that have influenced development in the past are not measurable in the present, even though they may have significantly influenced the course of development. Because the complexity and difficulty of observation, replication, and measurement complicate social science research, researchers must exercise great caution in generalizing from their studies. It is often necessary to conduct several studies in an area before attempting to formulate generalizations. If they consistently confirm initial findings, then researchers can be more confident in making broad generalizations.

Despite the handicaps, education and the social sciences have made great progress, and their scientific status can be expected to increase as scientific investigation and methodology become more systematic and rigorous.

THE NATURE OF RESEARCH

Scientific research is the application of the scientific approach to studying a problem. It is a way to acquire dependable and useful information. Its purpose is to discover answers to meaningful questions by applying scientific procedures. To be classified as scientific research, an investigation must involve the approach we described in the previous section. Although it may take place in different settings and may use different methods, scientific research is universally a systematic and objective search for reliable knowledge.

EDUCATIONAL RESEARCH

Educational research is the application of the scientific approach to the study of educational problems. Educational research is the way in which people acquire dependable and useful information about the educative process. Educators usually conduct research to find a solution to some problem or to gain insight into an issue they do not understand. The ultimate goal is to discover general principles or interpretations of behavior that people can use to explain, predict, and control events in educational situations—in other words, to formulate scientific theory.

The acceptance of the scientific approach in education and the other social sciences has lagged far behind its acceptance in the physical sciences. In 1897, J. M. Rice, a pioneer in educational research, found himself in a situation similar to that described by the quotation attributed to Bacon previously in this chapter. Rice asked the educators at the annual meeting of the National Education Association's Department of Superintendence if it would be possible to determine whether students who are given 40 minutes of spelling each day learn more than students given 10 minutes each day. Rice (1912) reported,

> To my great surprise, the question threw consternation into the camp. The first to respond was a very popular professor of psychology engaged in training teachers in the West. He said, in effect, that the question was one which could never be answered; and he gave me a rather severe drubbing for taking up the time of such an important body of educators in asking them silly questions. (pp. 17–18)

Rice did, in fact, collect empirical evidence on his question and found that the differences in achievement between those spending 10 minutes a day and those spending 40 minutes a day were negligible. He also pointed out that many words children were required to learn how to spell had little practical value. His work led other investigators, such as Edward L. Thorndike, to use documentary analysis to determine the frequency of use of words in the English language. Their work in turn led to improvements in language arts texts and curricula.

SUMMARY

Human beings have sought to acquire knowledge through experience, authority, deductive reasoning, inductive reasoning, and the scientific approach. The scientific approach is widely regarded as the single most reliable source of new knowledge.

The scientific approach rests on two basic assumptions: (1) People can derive truth from observation, and (2) phenomena conform to lawful relationships.

Scientific inquirers seek not absolute truth but, rather, theories that explain and predict phenomena in a reliable manner. They seek theories that are parsimonious, testable, and consistent, as well as theories that are themselves stimuli for further research. The scientific approach incorporates self-correction, inasmuch as every theory is tentative and may be set aside if a new theory better fits the evidence.

Investigators have used the scientific approach to explain, predict, and control physical phenomena for centuries. As a science, educational research uses investigative methods consistent with the basic procedures and operating conceptions of scientific inquiry. The complexity of educational variables and difficulties in making reliable observations impeded scientific inquiry in education. However, since the beginning of the movement early in the 20th century, scientific inquiry in education has enjoyed increasing acceptance and increasing success in both theoretical and practical research.

KEY CONCEPTS

deductive reasoning
hypothesis
imperfect induction
inductive reasoning
perfect induction
principle of parsimony
scientific approach
theory
universal determinism

EXERCISES

1. Identify the source of knowledge—*deductive reasoning, inductive reasoning*, or the *scientific approach*—most prominently used in the following examples:
   - **a.** After extensive observation of reactions, Lavoisier concluded that combustion is a process in which a burning substance combines with oxygen. His work was the death blow to the old phlogiston theory of burning.
   - **b.** Dalton, after much reflection, concluded that matter must consist of small particles called *atoms*. His early assumptions became the basis for the atomic theory.
   - **c.** Later scientists took Dalton's assumptions, made deductions from them, and proceeded to gather data that confirmed these assumptions. They found support for the atomic theory.
   - **d.** Knowing that radioactive substances constantly give off particles of energy without apparently reducing their mass, Einstein developed the formula $E = mc^2$ for converting matter into energy.
   - **e.** Accepting Einstein's theory, Fermi carried on experimentation that resulted in splitting the atom.
   - **f.** After studying reinforcement theory, a teacher hypothesizes that using a tutorial computer program will lead to superior achievement in arithmetic. She devises a study in which the tutorial is used with two sixth-grade classes, whereas conventional materials are used with two other sixth-grade classes.
2. What is the role of theory in scientific inquiry?
3. What is the difference between an inductive theory and a deductive theory?
4. Give examples of the use of authority and experience as sources of knowledge.
5. Evaluate the following deductive arguments:

   a. All graduating seniors with high GPAs study Latin. John is a senior with a high GPA. Therefore, John studies Latin.
   b. All vertebrates have backbones. This animal has a backbone. Therefore, this animal is a vertebrate.
6. Evaluate the following inductive arguments:
   a. This animal has a backbone. Animals with backbones are vertebrates. I am reasonably certain that this animal is a vertebrate.
   b. This is a student who studies very hard. Students who make good grades tend to study hard. This student probably makes good grades.
7. Which characteristic attitudes expected of scientists are violated in the following statements?
   a. This study was undertaken to prove that the use of marijuana is detrimental to academic achievement.
   b. It proved conclusively that this is the case.
   c. The results show that marijuana is evil.
8. What are the characteristics of a useful theory?
9. Which of the following would contribute to theory development in education?
   a. Evidence that supports the hypothesis of a study
   b. Evidence that refutes the hypothesis of a study
   c. (a) only
   d. (a) and (b)

ANSWERS

1. **a.** Inductive reasoning
   b. Deductive reasoning
   c. Scientific approach
   d. Deductive reasoning
   e. Scientific approach
   f. Scientific approach
2. Theory integrates findings, summarizes information, provides leads for new research, and enables people to explain and predict phenomena.
3. An inductive theory serves to explain previous observations, whereas a deductive theory is developed before extensive observations have been made.
4. Answers will vary.
5. **a.** The argument is flawed; the major premise is not valid.
   b. The argument is correct.
6. **a.** The argument is correct.
   b. The argument is flawed; cannot state that because the student studies hard, he or she makes good grades.
7. **a.** The scientist is objective and impartial.
   b. The scientist is skeptical and regards findings as tentative.
   c. The scientist deals with facts, not values.
8. A useful theory explains the phenomena in the simplest form possible, is consistent with observation and the established body of knowledge, provides means for its verification, and stimulates new investigation.
9. d

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