Scientific methods

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Content

Key Concepts

- Reliable scientific research requires the use of established procedures for conducting and evaluating experiments.
- Basic steps in scientific methods include identifying a problem, stating the problem, conducting background research, forming a hypothesis, designing a test, testing the hypothesis, and evaluating the results.
- Scientific methods involve a continual process that often incorporates changes to methodology in response to new information learned during experimentation.
- The experimental method must include experimental and control groups; variables testing; and the use of statistical analysis.
- If a discipline cannot apply scientific methods to the gaining of new knowledge, then that discipline cannot be considered as a science.

Strategies or uniform rules of procedure used in some scientific research with a measure of success. Scientific methods differ in generality, precision, and the extent to which they are scientifically justified. Thus, whereas the experimental method can in principle be used in all the sciences dealing with ascertainable facts, the various methods for measuring the electron charge are specific. The search for increasing quantitative precision involves the improvement or invention of special methods of measurement, also called techniques. All scientific methods are required to be compatible with confirmed scientific theories capable of explaining how the methods work. The most general of all the methods employed in science is called the scientific method.

The scientific method

All the sciences referring to real or putatively real things are supposed to abide by the scientific method. The latter may be summarized as the following sequence of steps: identification of a knowledge problem; precise formulation or reformulation of the problem; examination of the background knowledge in a search for items that might help solve the problem; choice or invention of a tentative hypothesis that looks promising; conceptual test of the hypothesis, that is, checking whether it is compatible with the bulk of the existing knowledge on the matter (for it might be a wild conjecture not worth pursuing); drawing some testable consequences of the hypothesis; design of an empirical (observational or experimental) test of the hypothesis or a consequence of it; actual empirical test of the hypothesis, involving a search for both favorable and unfavorable evidence (examples and counterexamples); critical examination and statistical processing of the data (for example, calculation of average error and elimination of outlying data); evaluation of the hypothesis in the light of its compatibility with both the background knowledge and the fresh empirical evidence; if the test results are inconclusive, design and performance of new tests, possibly using different special methods; if the test results are conclusive, acceptance, modification, or rejection of the hypothesis; if the hypothesis is acceptable, checking whether its acceptance forces some change (enrichment or correction) in the background knowledge; identifying and tackling new problems raised by the confirmed hypothesis; and repetition of the test and reexamination of its possible impact on existing knowledge. The case of the introduction and checking of new procedures is parallel, except that in this case reliability and accuracy, not truth, are at stake. So is the case of the introduction and checking of artifacts such as machines or organizations, except that in this case the checking is for efficiency. *See also:* **Systems engineering (/content/systems-engineering/676000)**

An alternative interpretation of the scientific method is as a sequence of problems. A typical example is the empirical problem of finding a particular value of a certain magnitude *M*, or the parallel theoretical problem of explaining why the value of *M* happens to be *m.* The experimenter's problem is to determine the measured value of *M* with relative error smaller than a preassigned number *e.* The theorist's problem is to determine what premises imply that the value of *M* is *m*, or whether *m* is to be found only by empirical means. The next experimental problem is to determine which experimental device would make it possible to measure *M* with error less than *e.* The corresponding theoretical problem is to determine which theory, subsidiary hypotheses, and data imply that *M* is worth *m.* A subsequent experimental problem is to determine the value of *M* that a measurement with the help of the chosen device yields. A corresponding theoretical problem is to determine the value of *M* according to the theory, subsidiary hypothesis, and data. From here on, the questions are addressed to both experimenter and theorist. They seek to find what the result implies or suggests; how the result could be corroborated independently, that is, by alternative procedures; whether the new result is more precise and plausible than the results obtained by alternative procedures; if so, what the result implies or suggests; and, if not, what may have to be altered in the preceding operations.

The experimental method

When the scientific method involves experiment, that is, the deliberate controlled modification of some properties (factors or variables), it is called the experimental method. This method involves the design and operation of an experimental setup. Such a setup often includes one or more measuring instruments. When the objects of experiment are very similar, they are compared before and after the variable or variables in question have been altered. When the objects of experiment exhibit significant variations, as is the case with organisms, in particular humans, a large collection of them must be studied. Every such collection is divided into two roughly equal parts: the experimental and the control groups. To avoid bias, the members of each collection are picked at random and, in the case of humans, the controls are given placebos. (In more refined experiments the control group is split into two, only one of which is given a placebo, and the experimenter does not know beforehand who will be given what.) Only the members of the experimental group are subjected to the stimulus whose effects the experimenter wishes to find out. The simplest experimental design involves the variation of one variable at a time. More complex experimental designs allow for the simultaneous variation of two or more variables. After the stimulus has been applied, the variables of interest are observed or measured in the two groups. If a difference is observed, a statistical significance test is applied to find out whether the difference is genuine or due to small individual differences or to random errors. The procedure is usually repeated by the same observer or by an independent investigator to check for possible errors in design, execution, or interpretation. *See also:* **Experiment (/content/experiment/248500)**; **Statistics (/content/statistics/652400)**

Discovering, inventing, and checking

The scientific method is not a recipe for making original discoveries or inventions; it does not prescribe the pathway that scientists must follow to attain success. Nor is it a substitute for creativity and resourcefulness. The actual pathway of scientific research is messy and partly at the mercy of unforeseen accidents, both lucky and unlucky. Moreover, this pathway depends on the subject matter as well as on the individual's imagination and experience. The goal of the scientific method is to ascertain whether a hypothesis is true to some degree. Indeed, the nucleus of the scientific method is the confrontation of an idea (hypothesis) with the facts it refers to, regardless of the source of the idea in question. In sum, the scientific method is a means for checking hypotheses for truth rather than for finding facts or inventing ideas.

The scientific method has not always been understood in this fashion. For instance, Francis Bacon and many others thought that the scientific method is a simple and guaranteed recipe for discovery and invention. But in fact no one has come up with any algorithms for having original ideas. (This is one of the reasons that it is impossible at present to design creative computers.) Others have denied the very existence of the scientific method.

Since this is a question concerning facts, it can only be resolved by an empirical investigation concerning the way that people actually conduct scientific research, regardless of what they say about method. Such investigation is bound to show that the answer depends on the kind of problem. Routine problems can indeed be handled with the help of well-tried special methods (techniques) that can be described almost exhaustively, so much so that their application can be entrusted to apprentices or technicians. Original problems are something utterly different. It requires originality and experience to find an open and interesting problem that can be investigated in a finite time with limited resources. Once a promising problem has been identified, it must be stated or perhaps reformulated in a precise way, and a tentative plan to work on it must be formulated —again, an original task. The invention of new hypotheses and new methods also takes inspiration and luck in addition to hard work and discussions with colleagues. Finally, the hypothesis must be checked in order to find out whether it is true to some degree, and the method must be tried out to ascertain whether it accomplishes what it purports do and, if so, whether it is better than rival techniques. It is here, in checking, that the scientific method plays a decisive and distinctive role. In short, the scientific method is the way that scientists proceed to check ideas and techniques, not invent them.

Reach of the scientific method

Whether the scientific method can legitimately and fruitfully be used in the social sciences, such as history, and in the socionatural or hybrid sciences, such as psychology and linguistics, has been a subject of controversy. The history of these sciences shows conclusively that the scientific method has been fruitful wherever it has actually been employed.

Test of scientificity

Since the use of the scientific method is one characteristic of scientific research, its absence is a sure indicator of nonscience. In other words, a discipline where the scientific method plays no role is not a science. Thus, such fields as theology, literary criticism, psychoanalysis, homeopathy, graphology, and palmistry can hardly be regarded as scientific. *See also:* **Empirical method (/content/empirical-method/231000)**; **Hypothesis (/content/hypothesis/334600)**; **Science (/content/science/607100)**

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Test Your Understanding

1. What is the purpose of a control group in a scientific experiment?
2. What is the next step in a scientific method if test results are conclusive?

3. Critical Thinking: Can a scientific method be used to prove with no uncertainty that something is and always will be true? Why or why not?

4. Critical Thinking: Describe some complications that may make it difficult to apply rigorous scientific methods to studies in the social sciences.

Links to Primary Literature

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Additional Readings

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