A TETRAHEDRON MODEL FOR RESEARCH

What course does your research take? Is it inductive, deductive, intuitive or even accidental? Build yourself a tetrahedron and find the sure route to success.

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RESEARCH is a much used term today not only by those involved in it but also by the general public. Such extensive use has resulted in frequent misunderstanding and misuse of the term. This misuse, which sometimes is deliberate, may lead someone to describe his activities as "conducting basic research on the ecologic and geographic factors affecting the anadromous salmo irideus, its feeding habits, and environment," when he is in fact fishing for rainbow trout.

To avoid such misuse one must recognize that research is *any* method that leads from known available facts to new acceptable facts. To the extent that research is controlled and guided toward specific goals it is scientific research. The scientific method is a particular way of conducting research and is subject to rules that are specific and communicable.

Some science courses do not even mention the scientific method; instead they concentrate on presenting more and more isolated facts and occasionally mention an experiment or observation. It is far more meaningful to appreciate the need for an expensive and difficult experiment than to remember the names, masses and relative distances of all the objects in the solar system. A plethora of facts is likely to bewilder the student and condition him to view science with awe.

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Build a tetrahedron

Let us consider a regular tetrahedron (figure 1) to help us visualize the relationships among the concepts I will discuss. In the diagram the vertices are labeled A, H, T and D, which stand for "Available pertinent facts," "Hypothesis," "Theory," and "Derived pertinent facts," respectively. The edges of the tetrahedron are labeled Observation, Experimentation, Mathematics and Accident. Each one of the edges represents a process that has a certain probability of success.

Each individual researcher can choose his own probabilities. A person with no mathematical training is likely to assign a very small value to the probability $P(HT)$ or to ask for help to increase it. I believe that physicists might assign the following relative magnitudes: $P(AH) = 10^{-2}$, $P(AT) = 10^{-7}$, $P(AD) = 10^{-12}$, $P(HT) = 10^{-1}$, $P(HD) = 10^{-5}$, $P(TD) = 10^{-1}$.

Figure 2 is a development of the surface of the tetrahedron with the faces labeled Deductive, Inductive, Intuitive and Empirical.

The object of research is to reach any pertinent derived facts D from some known available facts A. There are obviously several ways to achieve this, but each one has a different probability of success associated with it. On this basis one may identify several types of research.

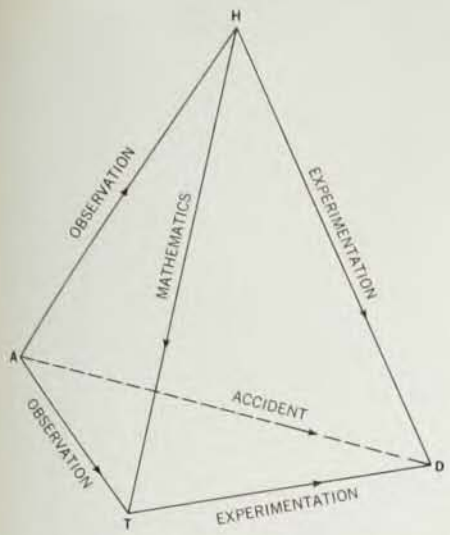
The straight line from A to D, research by accident, is the shortest path but has the smallest probability of success. As accidents can not be planned, this type of research is not very reliable. Furthermore it lacks the controlled, self-improving and self-perpetuating qualities needed in scientific research.

A more likely road to D is through T. This journey would happen if one were to make observations on the available facts, come up with a complete theory, and then through experimentation obtain pertinent derived facts. This route requires a great deal of intuition and luck, which are not very common. To arrive at a correct theory directly from available facts requires pure genius; because genius is a scarce commodity, this method is not relied upon very often as the main effort in scientific research.

Another way of doing research is to go through a hypothesis H to the desired end. But a hypothesis is only tentative and must be strengthened before it can be used for deriving new results. This path represents the empirical approach to research, wherein one collects data, formulates a hypothesis (consciously, or subconsciously), performs a quick experiment (sometimes omitted) and ends up proving nothing. This approach is very close to fishing. A lot of bait may be lost in trying to fish in an unknown pond. In other words one may risk a considerable sum of money and many man years collecting data and never show any new results. The method borders on scientific research but is only peripheral in its scope.

The only true path

Thus only one alternative is left among the pure approaches, that is path AHTD, which happens to be the longest one but has the greatest probability of success. This path represents the scientific method. It starts with a body of pertinent available facts A; then after careful observation a hy-



RESEARCH TETRAHEDRON. Arrows show direction of normal progress from available to derived facts. Relative probabilities of successful passage from one vertex to another vary widely; the path AHTD is most likely. —FIG. 1

pothesis H is formed that organizes and explains these observations. At this point mathematics (including logic) is brought to bear on the hypothesis, generalizing and strengthening it and eliminating inconsistencies. Thus one formulates a theory T that can now be tested with carefully chosen and planned experiments to yield new derived pertinent facts.

If the new facts disagree with the old, one checks each step in the process for errors before starting again. Even seemingly minor oversights have on occasion led to totally unacceptable results. Whenever the new facts are consistent with the old, the cycle is considered successful and the scientific method was used correctly. Once proven to be consistent the new facts become old facts and the cycle may be repeated.

No guidelines exist for the selection of the set of available facts with which to start a research effort. Similarly, once A is chosen there are no rules concerning the size and orientation of the tetrahedron. Because systematic advance along the path of the scientific method is always possible (though frequently difficult), it is the way most research progresses.

Only the scientific method is self-checking. One must use extreme care at each step, however, because there are many hypotheses (only one of which leads to the correct theory) and many facts (only some of which are pertinent in formulating a hypothesis). For the same reason the observations, mathematics and experiments must be chosen and used with care.

A researcher can use the elements of one process to enhance another. Experiments may be performed, for example, to increase the number of good observations, and mathematics may be used in planning experiments. This procedure occurs often and may obscure the proper location of the process on the path of the scientific method. The only way to recognize such secondary uses of the scientific processes is to have a full appreciation of the objectives and methods involved.

The research methods I discussed earlier are idealized or pure research processes using only the edges and vertices of the tetrahedron. Other paths through the interior and on the faces are possible and perhaps more frequent than the pure methods. If a researcher tends to depend on his intuition, his trip is likely to be near or on the intuitive plane. (If his "trip" is made under the influence of, say LSD, it may be purely intuitive and disconnected.) Pure induction has the maximal separation from derived facts, and pure deduction is most distant from available facts.

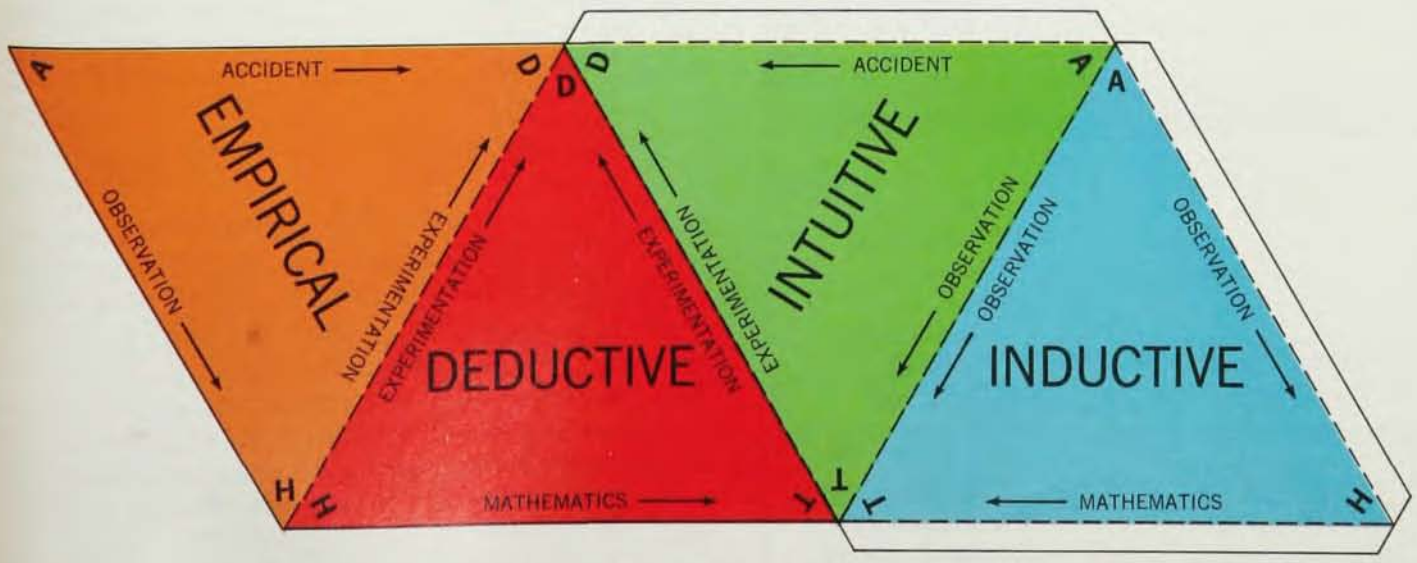
The reader may want to construct his own tetrahedron using figure 2 to plot his own research path, assigning appropriate weights for the location and probability of each leg. Similarly a research director may plot the paths followed by his researchers and thus obtain an estimate of where his group has strengths or weaknesses.

Just the facts, please

One must realize that the scientific method is a tool for obtaining new facts in a systematic and efficient manner; it can in no way replace facts.

More widespread awareness of the scentific method will benefit the progress and understanding of science and scientific research. It will result in derived facts of better quality and greater significance.

To recognize and remember facts is a sign of a conscious being; to organize and catalog large amounts of data is a sign of a thinking being; but to derive new facts is the privilege of the scientist. □



DEVELOPMENT OF THE TETRAHEDRON in a form suitable for cardboard construction. Cut along solid lines, score and fold along dotted lines, then tape or glue flaps. —FIG. 2