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# Experimentation: The acme of science

*La Experimentación: Cima de la Ciencia*

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## ABSTRACT

Although experimentation in science is universally celebrated as the acme of investigative disciplines, few analyses are made of such process. Consequently, opportunities have been lost for a better understanding of experimentation and science, as well as some potentialities for avoiding errors and achieving improvements of value to research. Suggestions are made for an improved analysis of experimentation.

DESCRIPTORS: experimentation, investigative disciplines, research, experimental analysis, scientific analysis.

## RESUMEN

*A pesar de que universalmente se considera a la experimentación como el pináculo de las disciplinas investigativas, pocos análisis se han hecho de este proceso. En consecuencia, se han perdido oportunidades para un mejor entendimiento de la experimentación y la ciencia, así como algunas potencialidades para evitar errores y lograr valiosas mejoras en la investigación. En el presente artículo se hacen sugerencias para un mejor análisis de la experimentación.*

*DESCRIPTORES: experimentación, disciplinas investigativas, investigación, análisis experimental, análisis científico.*

### *The Multiplexity of Science and Experimentation*

Among the great achievements of the human tribe the inception and development of science stands out as one of the brightest and most effective for the adaptation and welfare of mankind. There can be no doubt either that the utmost peaks of science are the experimental techniques, though much knowledge is also derived from casual contact with things and events. But since science and experimentation are the works of persons, they display many divergent facets, in the details of both methods and results. Consequently, there is as yet no discernible consensus as to the nature and scope of science and experimentation. Thus it is in order from time to time to pause and explore the problems and perfections of these enterprises.

*Science as Human Enterprise and as Cultural Institutions*

Semantically speaking, the term "science" refers to a number of important situations. First, of course, is that most significant field of activity in which individuals alone or in limited groups undertake to investigate the composition and the behavior of particular things and events. So with the growth of populations and resources there have developed numerous scientific specialists, astronomers, physicists, chemists, geologists, biologists, psychologists, sociologists, and many others. Proliferation of scientific experts proceeds as new objects and new types of behavior are discovered and become of interest to scientists.

With the accumulation of such searches and researches scientific types of institution arise and multiply-complex organizations are established such as laboratories, institutes, and universities with their personnel, plants, and sources of publications. In effecting these developments sponsors and supporters have a large share. Various governmental agencies or private endowments furnish the funds and prizes that make science a prominent feature of advanced cultural communities. From the intellectual standpoint scientific institutions consist of an accumulation of formalized propositions by small or large groups of specialists. Encyclopedias and handbooks are produced in profusion. Unanimity, however, is not a universal trait of scientific workers. They may differ widely on the basis of a lesser or greater adherence to traditional doctrine than to the things and events observed.

*Experimentation: The Peak Method of Science*

No scientist would dispute the contention that experimentation when possible is the most dependable and the most satisfactory means of obtaining knowledge about things and events. However, the complexities involved and the availability of access to experimental situations make prominent varying views concerning the specific procedures, the type of results obtained, and especially the interpretations made of the observed and recorded data.

No doubt the most weighty argument for approving and evaluating experimentation is that it guarantees the direct and immediate contact of the worker with the things and events studied. But even in the most favorable circumstances the question sometimes arises whether the things presumably observed actually exist. However, mistakes of identification do not occur so frequently as to diminish the value or efficacy of experimentation. Actually experimentation constitutes an unbroken continuum. Almost every type of contact with things and events lends itself to the experimental means of observation. But the mistake must be avoided of confusing experimentation with sheer manipulation. Experimentation is a specialized and expert form of manipulation usually requiring instruments and apparatus to accomplish. A catalogue of scientific instruments which lists an enormous number of simple and complex apparatus enforces the difference between the non experimental and experimental classes of manipulation.

### *The Logic of Experimentation*

Scientific experimentation is a logical, that is a systematic enterprise. There must be a fitting pattern of plan and performance. The experimenter must be well oriented with respect to the situation and circumstances in which he works. His hypotheses and operations must conform to his basic postulates. It is needless to add that he must be alert to the postulation under which his work is guided even if he himself does not or cannot verbalize or symbolize it.

### *Analysis of Experimentation Enterprises*

So important a feature of scientific work as experimentation clearly merits elaborate analysis as to its backgroud, methods, and the circumstances of its employment. Such an analysis will touch upon scientific, philosophical, and technological factors.

*Scientific factors.* Experimentation scientifically examined must take cognizance of the broad question whether the things and events to be studied actually exist or not. In modern physics the question arises as to whether light events are to be regarded as waves or corpuscles. Also questions arise as to the precise circumstances under which the events actually occur or maintain a definite temporary stability. A further problem concerns the suitability of the grades of precision which lend themselves to aplication of either laboratory and normal field investgation.

Above all no substitution of subject matter will provide information concerning the original things and events chosen for investigation. This type of substitution is much practiced by psychologists who reduce remembering to memorizing, and extremely complex behavior to reflexes, as well as making elaborate brain studies instead of working on various complex behavior fields. Probably the most flagrant type of substitution is that provoked by psychologists who substitute words for events. Terms like instinct, intelligence, consciousness, faculties, engrams are accepted as events to the neglect of what individuals actually do in their adaptations to things and events. But no less damaging to scientific work is the substitution of one type of object for another as when the brain is assumed to be a *mind* or the basis of a *mind,* so that the brain is loaded with centers, engrams and other verbally created mechanisms to explain and interpret the activities of organisms.

*Philosophical factors.* With respect to philosophy it is obvious that experimentation is always performed against a background of philosophical or metaphysical premises which may or may not be known to the workers concerned. Suggestive of this circumstance are the historical facts of physics and chemistry relevant to dispensing with forces, powers, and even theological interference with events. Similarly biology has had to counteract divine intervention in order to establish evolutional processes. It may only be concluded that experimentation must be as free as possible from the mass of epistemological and ontological views that pervade the intellectual domain of every society.

*Technological factors.* Scientific experimentation is applicable only to research with things and events that can be encountered as they occur. While some experimental work can be accomplished without elaborate technological support, that is not the case in other more complicated and more intricate event systems. Technological processes and products often are indispensable aids in the pursuit and achieving of knowledge. In every case the technological aspects of experimentation concern the production and employment of apparatus and instruments necessary for observation and the general access to the things and events under observation.

### *Experimentation in Theory and Practice*

While considering the range of experimental work, a distinction is often made between experimentation for theoretical science as over against experimentation upon practical problems. The basis for the distinction is merely the kind of information that is to be obtained, which in turn depends on the kind of data with which the experimenter works. Now since there is no such thing as a single unified experimental method, the distinction is modifiable on the basis of the kind of problem that is being worked upon. A good example of practical experimentation is that which is involved in medical practice. The use of the term practical does not detract from the criteria for experimentation which we have already discussed. No difference is to be sought in the ease of the methodology employed nor the importance of the situations in which the research is performed. To seek a cure for cancer or some other disease must be regarded as of equal importance with the research in the general nature of some phenomenon. A typical example of theoretical research is the discovery of the nature and activity of the astronomical phenomena called black holes.

Although it is not possible for any investigator to set up rigid and effective rules for any research, the scientist must be guided by general logic of science. It is interesting to point here to some classic rules for the conduct of reasoning and how to conduct oneself in investigating the facts of nature. For our purpose we indicate several celebrated systems of rules for achieving knowledge which are trustworthy and effective for many purposes. Our examples are from Francis Bacon (1561-1626), Rene Descartes (1596-1650), and Sir Isaac Newton (1642-1727).

*Bacon* (1620, 1905)

I. Man, being the servant and interpreter of Nature, can do and understand so much and so much only as he has observed in fact or in thought of the course of nature: beyond this he neither knows anything nor can he do anything.

II. Neither the naked hand nor the understanding left to itself can effect much. It is by instruments and helps that the work is done, which are as much wanted for the understanding as for the hand. And as the instruments of the hand either give motion or guide it, so the instruments of the mind supply either suggestions for the understanding or cautions.

III. Human knowledge and human power meet in one; for where the cause is not known the effect cannot be produced. Nature to be commanded must be obeyed; and that which in contemplation is as the cause is in operation as the rule.

VI. It would be an unsound fancy and self-contradictory to expect that things which have never yet been done can be done except by means which have never yet been tried.

VIII. Moreover the works already known are due to chance and experiment, rather than to sciences; for the sciences we now possess are merely systems for nice ordering and setting forth of things already invented; not methods of invention or directions for new work.

XII. The logic now in use serves rather to fix and give stability to the errors which have their foundation in commonly received notions than to help the search after truth. So it does more harm than good.

XIX. There are and can be only two ways of searching into and discovering truth. The one flies from the senses and particulars to the most general axioms, and from these principles, the truth of which it takes for settled and immovable, proceeds to judgment and to the discovery of middle axioms. And this way is now in fashion. The other derives axioms from the senses and particulars, rising by a gradual and unbroken ascent, so that it arrives at the most general axioms last of all. This is the true way, but as yet untried.

(Novum Organum, 1, 2, 3, 6, 8, 19), in Bacon 1905.

*Descartes* (1637, 1955)

The first of these was to accept nothing as true which I did not crearly recognize to be so; that is to say, carefully to avoid precipitation and prejudice in judgments, and to accept in them nothing more than what was presented to my mind so clearly and distinctly that I could have no occasion to doubt it.

The second was to divide up each of the difficulties which I examined into as many parts as possible, and as seemed requisite in order that it might be resolved in the best manner possible.

> The third was to carry on my reflections in due order, commencing with objects that were the most simple and easy to understand, in order to rise little, or by degrees, to knowledge of the most complex, assuming an order, even if a fictitious one, among those which do not follow a natural sequence relatively to one another.
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> The last was in all cases to make enumerations so complete and reviews so general that I should be certain of having omitted nothing. (Discourse on the Method of rightly conducting the reason and seeking for truth in the sciences, in Háldane and Ross, 1955).

*Newton* (1687, 1946)

> Rule I. We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances.
>
> Rule II. Therefore to the same natural effects we must, as far as possible, assign the same causes.
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> Rule III. The qualities of bodies, which admit neither intensification nor remission of degrees, and which are found to belong to all bodies within the reach of our experiments, are to be esteemed the universal qualities of all bodies whatsoever.
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> Rule IV. In experimental philosophy we are to look upon propositions inferred by general induction from phenomena as accurately or very nearly true, notwithstanding any contrary hypotheses that may be imagined, till such time as other phenomena occur, by which they may either be made more accurate, or liable to exceptions. (Rules of reasoning in Philosophy, Newton 1946).

## *Experimentation in Laboratory and Open-Field*

In the history of science there has been the viewpoint that experimentation is a method employed only in laboratories so that certain sciences were regarded as nonexperimental, for example astronomy and geology. Recently more critical analysis has been developed so that the idea of experimentation being only a laboratory procedure no longer is valid. In the case of astronomy and geology it is true that the objects and their behavior cannot be confined to a laboratory, however, the new discoveries concerning light and the development of the spectrometer as an instrument for analyzing chemical elements has shown that the use of these instruments in astronomy and the use of various other electronic instruments in geology must issue in the verdict that astronomy, geology as well as chemistry and physics are experimental sciences. We might indicate that those disciplines mentioned become experimental almost entirely by the employment of precise and effective instruments.

The incorrect differentiation has been made between experimental and field observation. This was mainly on the basis of considering only laboratory experiments as experimentation. Biologists differentiated between laboratory and field study until they developed a branch of their science called ethology, which emphasized the study of behavior of animals in their natural habitat. Gradually ethologists have undertaken to manipulate the natural conditions of animal colonies and individuals so that it is assuredly proper to speak of field experimentation. The term field here is not to be confused with the term in which units of action or behavior are either discovered or invented for analytic purposes.

*Essential Traits of Experimentation*

Despite the fact that experimentation is a sound and effective type of investigative technique, it is not always envisaged as the process it actually is. Frequently it is regarded as a magical wand to bring about guaranteed results and to confer universal excellence of judgment upon its practicioners. A listing of some of the main traits of experimentation may be helpful in avoiding erroneous views about this eminent technique of investigation.

*Extreme Specificity.* An important feature of scientific experimentation is its locus in particular situations. Its uniqueness is of course dependent upon the specificities of the problems it is employed to solve. There is no general and prefabricated pattern of plans and performances. Thus Sir George Thomson (1961, p. 137) goes so far as to say "that research is, in physics at least, very much a hit or miss affair." And most assuredly being a proficient experimenter confers no special merits of judgment upon the practicioners. A few examples illustrate this point. The first is that of a competent physicist, Sir Oliver Lodge.

*Adaptation to Data.* Sir Oliver Lodge who was so expert in dealing with electrical phenomena could not resist the temptation of believing in all sorts of mystical and transcendental processes. Being unfortunate enough to lose a favorite son in the first World War he believed that he could communicate with his dead son. His belief was just as strong about this impossible circumstance as the strength of his trusts in the occurrence of physical happenings. The lesson to be learned here is that experts in scientific experimentation do not always carry over their naturalistic attitudes into personal situations. It might be suggested here that physicists more than other scientists are prone to be split personalities so that the rules and principles of experimentation do not carry over to attitudes in other kinds of situations than laboratory observation.

A very striking illustration of illusory observation by another highly competent experimenter in physics is the case of Blondlot. This scientist more or less overcome with the wonders of X-rays and their discovery claimed to have observed another type of rays which he called N-rays. As J. J. Thompson (1937) comments other (French) observers besides Blondlot claimed to have observed these N-rays, but since no English physicist could detect such rays it was generally concluded that the observations of Blondlot were illusory.

An instructive example of a psychologist and psychiatrist developing insubstantial concepts about experimentation is at hand in the case of Moore (1939) author of a volume entitled, *Cognitive Psychology.* This writer who happened to be a monk of the order of St. Benedict in addition to being a physician and an experimental psychologist, cited many experiments in psychological behavior and concluded that they all demonstrated the reality of psychical processes. A critic could easily conclude that it was Moore's religious philosophy that influenced him. Actually it was unnecessary for Moore to do experiments because he started with the conviction that there existed a psyche or soul so that everything that the subjects in the experiments did would point to the existence of such a psyche or soul.

*Operators and Operations in Experimentation.* After the great development of relativity and quantum mechanics physicists originated and developed a branch of their discipline devoted to the study of minute atomic phenomena. Although physicists are classical experimenters and to a certain extent teachers of experimentation to members of the other disciplines, they were so overwhelmed by the difficulties of atomic or microscopic physics that they established a principle that scientific observation always combined external events with the procedures of the observers. A prominent theoretician of this persuasion, Niels Bohr (1958), formulated the notion that what a microscopic physicist was observing was in part himself. Now it must be agreed that all experimentation involves the ideas and the activities of observers or experimenters, but it is impossible to overlook the fact that in the final analysis the end and aim of the experimenter is to develop knowledge about events. It may be necessary for an experimenter to admit that his findings are based on his apparatus and upon his hypotheses, but that is not to accept any mystical idea of observing a mixture of oneself and of stimulating objects.

In case an experimenter is obliged to specify the unavailability of certain events so that a bit of substitution is necessary for obtaining a modicum of information, he is required to state the proportion of independent event to added construction. This may diminish the confidence in the validity of his findings so far as the total research is concerned. An excellent exhibit is the famous spectrum experiment of Newton. It must be plain that Newton made the excusable mistake in his age of assuming that color was partially and potentially contained in the light and not produced by his insertion of a glass prism into a beam of light rays or corpuscles.

### *Cultural Influences on Experimentation*

Experimentation in science though presumed to be strictly influenced only by the nature of the things and events investigated is still goberned in various ways by established traditions. An important example is the subtle influence of cultural institutions, so that in some cases experimentation is forbidden or at least looked down upon. A milder form of influence consists of being wittingly or unwittingly swayed by the traditions of a prevalent type of discipline, and the style of work which has developed in that discipline.

The history of quantum theory in physics illustrates both types of influence. The former is illustrated by the massive opposition to constructing propositions outside the range of classical Newtonian mechanics. It is well know how opposed Planck (1858-1947) (1949) the initiator of the quantum theory, was himself to the acceptance of the new findings concerning black body radiation. It was difficult for him to realize that energy could be discontinuous so that the conception of quanta had to be introduced into the new physics concerned with microscopic events.

In the field of psychology, history relates the great dichotomy that Wundt postulated between what he called the Geisteswissenschaften and the Naturwissenschaften. In the latter case it is clear that Wundt was influenced by the prevalent but aberrant mind-body dogma. Otherwise he might have grasped the fact that events could be differently structured and hence operate differently.

Another illustration of the influence of traditions on observational and interpretational propositions is illuminated by conditions in psychoneurology. Here is an example. Following the acceptance of the postulation that the brain substitutes for the soul, students of psychology perform many experiments on the brain, destroying parts to test the assumption that the brain consists of centers or engrams. An example is foud in the work of Carlyle Jacobson and others who ablated the frontal lobes of monkeys to see if that would affect their performance of delayed reactions. His conclusion was that the frontal lobes are the seat of the capacity to perform such actions. Although psychological experiments are usually not repeated, that is not the case in this situation, and so another worker, Malmo (1942), repeated this experiment with the exception that the he turned off the lights and the animal could do the action. Despite the need for a new conclusion about the brain, writers on neuropsychology still refer to Jacobson's results without mentioning the invalidity discovered during the repetition of the experiment.

*Incidental Influences on Experimentation*

So intricate a procedure as experimentation is further complicated by extrinsic conditions upon occasion. Perhaps most of the outstanding examples relate to problems of apparatus. When apparatus is acquired with difficulty and expense there may be a tendency to allow it to be used more extensively than the events or situations demand. Also an interesting and important laboratory situation may influence workers to persist in accumulating data beyond reasonable necessity and the neglect of more important matters.

*Summary*

While scientific experimentation is of the greatest perfection in the general search for orientation and knowledge both its merits and shortcomings are functions of human and cultural circumstances. Moreover, despite the multiplexity of experimental designs necessary to cover the specificities of experimental enterprises it is still possible to list some general specifications as criteria for valid and productive additions to the stock of scientific information.

*Systematic Fields.* Scientific experimentation must always comprise a systematic field. Almost always a research involves numerous factors or variables and it is a test of a valid experimental system that enough variables are considered to make the system valid and meaningful on the basis of the things and events involved plus the conditions which influence the type of behavior observed. Of course it is not easy to make sure that all of the necessary variables are placed under consideration. But it may be certain that no general mystical factors are included in the system.

*Naturalistic orientation.* To make sure that the experimental situation is properly considered and the recorded system, valid no room can be left for any thing or event that cannot be confronted either directly, through instruments, or through proper inference.

*Postulation accords with events.* Since all experimental situations include events and constructs, due care must be taken that the postulates are just as close to events as possible in specific situations. In psychology, for example, postulation may not include forces or powers or intervening events. Such a mixture of observational events with stimulus object events invariably destroys the validity of the experimental systems involved. Similar harmonies must exist with respect to interpretations made with respect to events and operations.

*Range of knowledge in scientific experimentation.* Since all absolutes of every kind are excluded from scientific systems, all observations and theories are relative to the events observed and the means of observation. Probably the most obvious form of knowledge arises from the direct contact with things and events. But there are many other partial observations which are completed by inferences drawn from the same or similar kinds of situations.

The range of knowledge is as broad as the kinds of fields that are under consideration. They depend upon the events in the first instance and then upon the value of the observations. The latter in turn depend of course upon technological situations, the availibility of instruments, and the techniques of constructing such instruments or apparatus as are required for a particular experimental problem.

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