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MEDICAL AND OTHER SCIENCES[1]

AN INQUIRY OF WHAT IS SCIENCE WHEN IS IT TAUGHT SCIENTIFICALLY

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SCIENCE to-day plays an intricate, permeating and dominant rôle in our lives. It is not my intention to weary you with evidence in support of this thesis, to list the names of the various agencies engaged in science or the numbers of men and women so engaged or the ever-increasing millions of dollars expended, or to name the institutions, industries, occupations, mental attitudes and thoughts profoundly modified by science. Nor will I cite the figures of the ever-increasing numbers of "students" or numbers of hours or increasing budgets for science teaching from kindergarten to university. Nor is it necessary to list the amazing increase in the number of journals of science or the bewildering increase in the number of published manuscripts, the despair of the librarian as well as of the scientist. There is to-day probably no field of human endeavor which is not affected by the advances in science. Truly may it be said that science plays a dominant rôle in our lives.

It might then be assumed that the meaning of science, its essential characteristics, the tests by which it may be distinguished from pseudoscience or non-science, the methods of teaching science scientifically would be widely and clearly understood. The startling fact, however, is that science is probably more widely not understood or misunderstood than in any previous period of history. Misunderstood not only by the armies of schooled (so-called educated) masses, but by the teachers and practitioners of science. The extent to which unscientific science is taught in our schools is amazing.

[1] Address of the retiring vice-president and chairman of Section N—Medical Sciences, American Association for the Advancement of Science, Des Moines, Iowa, December, 1929.

It is widely believed that chemistry, agriculture, medicine, etc., are coequal with the sciences of advertising, linguistics, archeology, music, literature; that the science of paleontology belongs to the same brood as salesmanship and labor unionism; that the science of engineering is akin to the science of voice placement, taxonomy, crime, anatomy, history, religion, sociology, physiology, plumbing, Christian science, *ad nauseam*. One is amused, chagrined, disgusted, according to one's temperament.

All of you may admit biochemistry, physiology, mathematics into the realm of sciences. Some of you may grudgingly tolerate some branches of medicine, engineering, agriculture. Few will concede a place for history, philology, salesmanship. Probably none will yield a place to plumbing, Christian science, painting. But would there be agreement among you? Think of the disagreement among the schooled ("educated") members of our population.

Is science definable? Is it a fixed entity, like dollar, mile, gram; or is it a variable entity, whose limits may be defined, such as color, sound, taste, insurance rates; or is science an entity whose limits may not be clearly defined, such as instinct, thought, government, religion, art, etc.? Is it knowledge or only certain categories of knowledge or is it not knowledge at all?

Science, like paleontology and civilization, embraces a historical series from the simple to the complex. The earliest and most primitive stage may be characterized by the accumulation of new and exact facts or observations, but seen through eyes beclouded and distorted by beliefs in the ubiquitous and ever-present gods, demons, spirits dominating and controlling man and his environment.

A later stage in the development of science may be characterized by the systematization of such accumulated facts, or the formulation of "laws" such as the laws of alchemy, the Ptolemaic laws in astronomy, the pre-Galenic laws in medicine, the Aristotelian laws of nature. These were interesting mixtures of rare insight, exact and inexact description, mythology, hearsay evidence, unverified and unverifiable facts and laws—all subject to the whims of gods, saints and spirits.

The next stage in the evolution of science consisted in the gradual elimination of anthropomorphism and deism both from observation of facts and formulations of laws, but yet unverified and unverifiable, such as the bizarre pharmacopoeias up to the eighteenth century, the theories of evolution prior to Lamarck, the systems of classification including Linnaeus, the later alchemy.

Mathematics had in the meantime been developing most rapidly. Starting with immutable and absolute truths, the science of mathematics grew by further testing and elaboration of these fundamental truths.

The next great development in the natural sciences arose with the growth of chemistry and physics. It no longer sufficed to accumulate facts or observations, or to elaborate unverified and unverifiable laws or to hypothecate causes. The new era in science demanded experimentation, *i.e.*, the determination of the immediate or proximate mechanistic cause or causes of the phenomenon. The scientist started with observations or facts. He then devised an experiment in which the profoundly complex conditions associated with a phenomenon were reduced to constancy or were known. Only one condition or factor was unknown. The experimental conditions differed from the control conditions by this one, simple or compound, unknown factor. The object was to determine the rôle of this unknown or x in the phenomenon. He must produce or modify the phenomenon at will, to obtain the same results, under the same experimental conditions. From such experiments, new phenomena or new unknowns or new methods of analysis of the x arose, which new x must again be tested by suitable experimentation. The attitude of mind, the experimental procedure which enabled one to determine the unknown x, became the dominant characteristic of science. Facts were the initial step. The experiment as above defined became the sesame to solve certain riddles of the universe.

All these and intermediate stages in the development of science coexist, as do the different stages in the evolution of organisms or of civilizations. The confusion lies in the assumption that the aims, the methods, the mental attitudes, the values of each stage of science are the same. They are no more alike than are the ameba and man, the shepherd age of early Biblical times and the industrial age of 1900. Each stage is real, useful in its sphere, instructive, is a discipline, but they are not equal or alike.

The fact-seeking stage is the amebic stage in the development of science. The law-formulating stage is likewise primitive. The stage of unverifiable facts and laws also belongs to the primitive era of science. The experimental stage, provided it be properly defined, is not only more complex, more modern, but is different from the primitive stages of science. The experimental method, properly defined, characterizes real science and differentiates it from primitive science, from pseudoscience, from non-science, from anti-science.

A few examples may make the meaning more clear. If one describes or catalogues diseases into a nosological system or the species of animals or plants by the rules of classification or the parts of an organism by morphological, histological or embryological rules,

one is said to be engaged in science. By the same token the description and cataloguing into a rational system of pigments, lights and brushes would make one an artist. The description and cataloguing of dramas or poems should make one a dramatist or poet. If description and cataloguing of facts into a rational system constitutes science, then the dictionary, the encyclopedia, books of knowledge, outlines of science, survey courses, commercial descriptive catalogues of chemicals, of apparatus, of supplies, of dogs, of dresses, materia medica, hardware or any other body of systematized knowledge—then all these constitute the quintessence of science. Confusion is doubly confounded by including collections of facts in so-called science theses, projects and "researches," from grammar grade to university inclusive.

These collections of facts do not constitute science. At best they are the prelude to science, the building-blocks with which the structure of science is built.

It must not be forgotten that facts and laws are triumphs of a day, reigning to-day, dethroned to-morrow. To-day we believe in Euclidean geometry; to-morrow there is non-Euclidean geometry. To-day it is gravity; to-morrow relativity. To-day we worship calories; to-morrow vitamins and hormones. To-day we enthrone proteins; to-morrow amino acids. To-day we hail the telephone, to-morrow radio. To-day we have found absolute truth in the atom; to-morrow the ion and electron. To-day it is humors and *mal* air, to-morrow it is germs and mosquitoes. Facts and laws and truths change. That which reigns forever is the method of science, the experimental method, true to-day, to-morrow and all time.

It is alleged by many that expertness, or ability to do things resulting from knowledge, is science. Technical ability in making a good slide, or good dissection, a good surgical operation, a chemical analysis, an exercise in physics, constitutes science. By the same logic, the good bricklayer, plumber, builder, artificial flower maker, tailor, gardener, furrier, the butcher, the cook, the surveyor, the cement mixer, the analyzer of sputums and urines, etc., etc., all belong to the brotherhood of science.

It is not my intention to belittle the courses in so-called fact science or to minimize the usefulness of facts, or to detract one iota from the glory of the distinguished men teaching the sciences by this method. It is my intention, however, to point out as clearly as I can, that such courses, such methods represent the earliest, most primitive stages in the dawn of science. To substitute the accumulation of facts and "laws" or dexterity of manipulation for experimental methodology is naïve, erroneous, anti-science, the cartoon of science.

Do you realize how extensively this "fact" and "law" worship dominates our courses in science, not only in high schools, not only in colleges, not only in professional schools of dentistry, medicine, engineering, chemistry, but even in universities? Wherein is the factual method in these science courses different from the factual method in theology, esthetics, literature, art, history, etc.?

I have studied text-books, laboratory directions and laboratory manuals; I have talked with teachers of nearly all grades in all parts of the country, to find out to what extent real, scientific, experimental methodology is used in our laboratories. I find "scientific" dogmas, primitive fact-finding methods, automaton cook-book manipulations, the almost exclusive concentration on facts, more facts and yet more facts. The prevailing method is the archaic or Cambrian stage in the development of science. This archaic devotion to facts and cook-book manipulation parading under the banner of science pervades grammar school to university inclusive.

If time and occasion permitted I would like to cite the innumerable examples from laboratory manuals. In chemistry I can not distinguish any fundamental difference in method from that pursued by my cook in making a new recipe. In physics with elaborate tools for exact measurement I can not distinguish any fundamental difference in method from that pursued by the carpenter, mason, surveyor, builder, auto mechanic, also using tools of precision and following directions at least as intelligently. In biology and many medical courses, the student is told to observe this, that and the other structure, symptom or behavior. The same mental processes are involved as in pre-Darwinian, pre-Galenic days. The terminology and apparatus are different; the method of evaluating evidence is the same. The same emphasis on observation, the same acceptance of facts and theories, the same kind of assumptions concerning causes.

It is conceded that primitive science is a necessary stage in the training process. It is not conceded that primitive methods should occupy all or nearly all the years from grammar school to university.

In what courses of science is the student expected to frame his own question, find suitable materials (including bibliography) and apparatus, devise his own experiment, analyze the conditions, arrange one set of conditions where all are constant or known, another where only one condition or factor is unknown, to vary this unknown x, to solve for x, *i.e.*, to find the immediate cause of the phenomenon? To determine not facts or laws, but the condition or conditions under which a phenomenon can be made to appear? To get the same results, to deduce proper conclusions from the experimental data, to watch for

the crucial exception, so significant as a clue to further resolution of the constituent conditions, to plan the next experiment? Where is it taught that not facts or tools or materials or technique, but the method of experimental investigation is the test of scientific procedure?

It is not asserted that all science courses are conducted by the methods of the dark ages. There are beautiful examples of the highest type of experimental courses and investigation. It is asserted that such examples are ominously few. The astounding thing is that so many men, distinguished and honored for the splendid use of the best experimental methods in their own investigations, seem satisfied with the methods of bygone ages so far as the students in their courses are concerned.

One is astounded or amused by the wide use of the terms, the phraseology, the apparatus, the motions, the externalia of experimental procedure in our courses. These but thinly disguise the underlying dogma, cook-book manipulations, unverified or unverifiable conclusions, the methodology of non-science or anti-science. There is far too little of the real spirit of experimental investigation.

I take issue with the one who asserts that the methods of experimental investigation must be postponed to the Ph.D. thesis. I submit that the method can and should be used not only in the Ph.D. thesis, but also in most graduate science courses, in most undergraduate science courses, in most science courses of junior college, high school and grammar school. As a matter of fact, but far too infrequently, one finds splendid examples of true experimental investigation in all these grades of schools.

If it be contended that the spirit is willing but the flesh is weak, that real methods of experimentation can not be taught in classes of 100, 200, 400 and more, where part-time, inadequately and often narrowly trained student and graduate assistants do the teaching, I would agree wholeheartedly with you. If the large numbers of students, crowded schedules of the teachers, etc., prevent true teaching of science, then let it be proclaimed on every hand, on every occasion, let it be clearly understood by all, that what we are teaching is either not science at all or only the lower levels of science. Let it be clearly understood that we are training in modern laboratories, with modern tools and phraseology, by the standards of pre-Galen, pre-Vesalius, pre-Lavoisier, pre-Galileo, pre-Darwin, pre-Bacon, pre-Pasteur.

Maltraining like malnutrition, if long continued, has very serious and lasting effects on the organism—not only upon the large armies of college students but upon the relatively small number of selected (often self-selected) individuals who constitute the professional workers in science. My own experience as editor is in agreement with that of the editors of high exemplars of scientific journals. It is no secret, yet not widely known, how large is the proportion of manuscripts returned to authors not only for minor changes such as clearness of style, form, citations, English, etc., but for major and serious defects, such as inadequate controls, inadequate experimental procedure, inadequate proof that the phenomenon is due to the one variable cited, inadequate or overreaching conclusions from the data submitted. In other words, for lack of understanding of the basic qualities that constitute experimental science. It has been widely urged, and not facetiously, that even more rigid exclusion of manuscripts should be practiced.

Permit me to make brief reference to another related problem. For many years, probably from the time when Latin was the medium of communication by the learned, with increasing nationalism, the rapid specialization of the sciences, the multiplicity of societies, journals and meetings, the rise of science in more and more lands, with corresponding language difficulties, with the barriers created by hosts of new terminologies and elaborate technical procedures, there resulted a series of intellectual barriers that separated the workers into narrower and narrower fields. Such separatism is accentuated in our colleges and universities by the physical separation of departments and subdepartments in different parts of the campus, or, equally effectual, different floors of the same building, and much too frequently by unfriendly doors on the same floor. Each worker or group of workers conducts his researches and courses as though the allied divisions of science were wholly unrelated entities. And inevitably lack of understanding, misunderstanding, duplication, lost motion are correspondingly increased. To be sure, this separatism is not confined to the sciences.

In latter years there have been a number of movements directed to bringing together into cooperative action the workers in allied fields. This section, I believe, was the first among the sections in the American Association for the Advancement of Science to develop and champion such a movement. In 1920 I was honored by election to the secretaryship. During the next seven years, with the closest cooperation of the distinguished members of the section committee, we developed this program. We endeavored to bring together workers in related fields to discuss common and borderline problems. The section committee was selected so that one or more representatives of the different fields of medicine, parasitology, medical entomology, anthropology, vital statistics, veterinary science, medical practice, etc., were members of the committee. The programs were built on the same

principle, by careful inquiry of the section committee and others as to the important problems significant to workers in several fields, the outstanding investigators of these problems, the groups that should be invited to cooperate with us to the end that common or borderline problems might be discussed by workers in allied fields. The new policy met with immediate and wide and hearty response.

There were, of course, other efforts by other groups in the same general direction, a breaking down of ever-narrowing barriers, a regrouping and coming together of isolated groups. The Society for Experimental Biology and Medicine has for twenty-six years been bringing together the workers in the manifold fields of experimental medicine and biology. The geneticists are coming together more and more closely each year, and breaking down the artificial walls called zoology, botany, agriculture, etc. The National Academy, the American Philosophical Society, some of the state academies, are but a few illustrations. An interesting example is the union of chemists, physiologists, pathologists and biologists with the surgeons in the Mayo Foundation. The Rockefeller Institute more completely and on a larger scale than ever before (except in war) uses every field, every tool, every facility, and by frequent group meetings attacks the fundamental problems of health and disease. The Carnegie Institution is another illustrious example of coordinated attack on the problems of science. An increasing number of university laboratories, particularly in medical schools as well as industrial laboratories, are being manned and equipped with workers and tools from the allied fields of science. There is a wholesome trend in the same direction in respect to newly organized journals. More and more are the old barriers laid low, regrouping of workers, cooperative use of tools, techniques, cooperation of workers.

In the Cambrian or Precambrian age in which so many of our schools still live, one finds evidences of the ancient separatisms, the old fear of the trespasser, the vicious codes that separate related departments and subdivisions of science, that compel uncorrelated, compartmented, often antagonistic or contradictory facts, methods and results of science.

There are a number of movements making for concerted attacks on important problems by workers in allied fields. There are examples in the drama, in archeology, in exploration, in two or three colleges, in some university laboratories, in many research institutes, in a few grammar and high schools. These are oases surrounded and overwhelmed by the blare of publicity trumpets, proclaiming the polytheism of the sciences, shouting the shibboleths of experiment, project, research, scientific method, integration, survey courses and other fine names for rather poor substitutes of the original article.

When so many ills are believed to be curable not by medicine, but by legislation, we might urge a law like the Food and Drug Act, penalizing institutions of learning which put misleading labels on their wares —a law as unenforceable as many other laws.

May the time come soon when the practitioners of science, individually and collectively as faculties, may more widely and more adequately understand the aims, the methods, the importance of experimental investigation in science, its significance in education, in citizenship. We may then hope that trustees, presidents and heads of government laboratories will cooperate more and more in providing the conditions that will make for better, more thorough methods in teaching science, when emphasis will be transferred increasingly from the search for facts and "laws" to the search for rigorous experimental procedures.

We may then hope for a better understanding of science by larger proportions of our people, expect decreasing influence of faddists and stylists, less opposition and more cooperation from the public that conditions our lives, whether legislature, press, industrial and financial leaders, publicists, medical workers, etc.

We may then hope for a more rapid cure of the ills that the individual and democracy are heir to.

SOME OBSERVATIONS FROM LIMING INVESTIGATIONS[1]

By Professor C. A. MOOERS

TENNESSEE AGRICULTURAL EXPERIMENT STATION

LIMING to increase crop production has been practiced in various parts of the world from time immemorial. The practice, however, appears to have been somewhat intermittent, and in Europe, as well as in this country, many farmers have never limed. The custom of liming gave rise to some disquieting adages, such as "Liming enriches the father but impoverishes the son" and "Lime and marl without manure make both farm and farmer poor."

Soon after the advent of the agricultural experiment stations liming became a subject of investiga-

[1] Address of the retiring vice-president and chairman of Section O—Agriculture, American Association for the Advancement of Science, Des Moines, December 28, 1929.