SCIENCE

FRIDAY, SEPTEMBER 14, 1917

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ORGANIZED KNOWLEDGE AND NATIONAL WELFARE[1]

THE future of any nation is secure if it lives up to its possibilities. The nation which does this is bound to be a leader among nations and to command world-wide respect. Its national problems will be solved and solved intelligently and thoroughly. The greatness of a man is in part born in him and in part the product of his environment. According to eminent biologists, he is about two fifths born and three fifths made. Similarly, a nation is great according to its resources and according to its development of these resources. And the development of those resources may be accomplished only through organized knowledge.

I. *The Function of Organized Knowledge.*—Consider for a moment two manufacturing concerns on an equal footing as regards output, but of which one is continually making progress through improvements in manufacturing processes, developing new and valuable products and investigating the fundamental principles underlying all these processes. This firm will in time outstrip the other in every way; the balance, in fact, is a very delicate one, since the results are cumulative. In quite a similar manner, that nation will advance to leadership in which the increase in organized knowledge and the application of that knowledge are greatest. For this reason, interest in research should be as wide as the nation and should cover the

[1] Abstract of an address given April 9, 1917, to the Associated Engineering Societies of Worcester.

whole gamut of problems from administration to agriculture, from medicine to manufacture. For it is only through the solution of individual problems that general principles can be arrived at and the sum total of useful organized knowledge increased.

It is essential that the wide field to be covered be kept in mind, extending over not only physics, chemistry, engineering and all their branches, but all the biological and mental sciences as well. In the last analysis an increase in knowledge in the field of the *biological sciences* means more and better food, improved racial stock and improved public health as well as increased material welfare in all having to do with plants and animals. Increased knowledge of the fundamental principles of the *mental sciences* means increased efficiency in administration, legislation, education, operation and research. I do not mean mere book learning in psychology, but such a command of the fundamental principles as will assist in the solution of all practical problems. Increased knowledge of *chemistry* means increased ability to utilize raw materials and an improvement in general health and living conditions. One may almost say that the generalized problem of chemistry is to convert the less expensive raw materials such as cellulose, petroleum, glucose, various minerals and oils, starch, nitrogen of the air and the like into food, clothing, tools for our use and means for national defense. An application of the fundamental principles of *physics* in the way of various engineering problems leads to a fuller utilization of resources, new products useful to man, makes inventions possible and effective and adds to the general increase in operating efficiency in every way.

The utilization of organized knowledge in national welfare comes about both through knowledge itself and the incentive to apply that knowledge. Both ability and incentive are essential to utilization. So far as knowledge went, we might have made dyes and optical glass many years ago in this country, but since they could be bought so cheaply there was no incentive to develop the manufacture of such articles. These are cases of ability without incentive. On the other hand, there has long been an incentive for the fixation of nitrogen and for various mechanical devices, but these have not been forthcoming for lack of sufficient knowledge.

The incentive to do our best, to live up to our possibilities as a nation or as individuals may be classed as either psychic or commercial. In the last analysis, the tendency towards doing our best is hardly more than a rudimentary instinct. The commercial incentive is a matter of either supplying our direct needs or supplying some one else's needs for a consideration. The psychic incentives to put forth our best efforts may be classed under the heads of emulation, contact, contract and struggle for existence. A great many students enter research because their favorite professors have made reputations in research or because their friends and colleagues are doing such work. Incentive by *contact* covers the psychology of getting started at the line of work you wish to become interested in. It is well known that the work itself produces a reaction on one's mind which makes it much easier to continue the work. Exactly, this form of stimulus is experienced in writing a scientific paper, for example. Incentive by *contract* to put forth our best efforts comes from putting ourselves under obligation to produce certain results. The substance of this lecture has been in my mind for many years, but it would never have been prepared but for my having undertaken to talk on this subject. This is a typical example of polarization by contract. Finally, the incentive of stern necessity or what we consider necessity is perhaps the most powerful of all in both research and application. All who have families to support and needs to be supplied know full well the stimulus which comes from them.

In general, in normal times it is perhaps no exaggeration to say that neither the average individual nor the average nation approaches within fifty per cent. of its possibilities. Nothing short of a war threatening the national existence can shake a nation out of its lethargy. Similarly, the average individual can not be induced to put forth his best efforts without the strongest of incentives. It is unfortunate that this is the case. However, with sufficient attention given to the problem by trained experts in mental science, it is quite possible that at some future date as high as sixty or eighty per cent. of the possibilites may be realized without any appeal to arms for the nation or any unusual incentive for the individual.

II. *The Increase of Organized Knowledge.*—The research by which organized knowledge is increased will doubtless always be carried on chiefly by three distinct types of research organizations: research by the government in national laboratories, research by the universities in connection with the work of instruction and research by industrial laboratories in connection with the interests of manufacturing concerns. Aside from these three main classes of laboratories there will always be large, privately endowed research organizations, dealing with neglected fields of remote commercial interest, private industrial laboratories supported by consulting fees and cooperative testing laboratories also self sustaining.

National, industrial and university research follow three essentially different lines. There is considerable overlap in field, it is true, but each is centered on a different kind of research. The proper function of national research is the solution of such problems as concern the nation as a whole, affect the general interests of all classes of individuals; it is the custodian of standards, it develops methods of precise measurements and investigation, it is trouble engineer for the solution of very difficult problems or the problems of producing units so small as not to be able to have their own research laboratories. It is the proper guardian of the public health. It solves problems connected with contagious and vocational diseases. It develops methods of making good roads, increasing the fertility of the soil and stocking waters with fish. National research is of all grades from that dealing with fundamental principles up to that relating merely to lessening the costs of production.

University research must always, in the very nature of things, be concerned chiefly with the advancement of the various sciences as such, and with the development of the fundamental principles of each science. The best university instruction is along these lines and investigators and students in close touch with them will naturally have most new ideas in close connection with fundamental principles. University research is necessarily one of small jobs and the best minds and is without very much continuity. The advanced student is interested in a research just long enough to make it acceptable as a doctor's thesis. The instructor is too burdened with teaching to give more than a margin of time to research. But a very small part of the university research is extended year after year covering a wide field. This is quite as it should be, the university looking after those fields of research of little commercial value, on the one hand, and not directly affecting the interests of the nation as a whole, on the other, but of fundamental and far reaching importance to all.

Industrial research takes the middle ground and has already become a distinct profession. It is in close touch with practical commercial application, on the one hand, and with fundamental principles, on the other. Its proper field is anything between elimination of works troubles and the investigation of fundamental principles. The staff of the ideal industrial research laboratory is composed of experts of wide experience who can serve the manufacturing departments in a consulting capacity without sacrifice of time. We may perhaps best summarize the preceding statements by describing the ideal research man and the ideal research laboratory.

Some writers have spoken of the investigator as a rare individual to be sifted out from educational institutions with great care for a particular line of work. My personal opinion is that a large percentage of the men students are fitted for research work if properly started along the right line. The investigator should have a mind at once fertile and well trained. His mind should be teeming with new ideas, but he should possess unerring judgment to reject those which are not logical or promising. We are often asked what sort of preparation in physics would be best for men intending to take up research as a life work. It has even been proposed to give courses in "applied physics" for the benefit of those intending to take up industrial research. Our invariable reply is that the best preparation for a research man is a thorough grounding in the fundamental principles of his science: physics, chemistry or whatever it may be. If he has this thorough knowledge of fundamental principles it is safe to say that in any properly organized research laboratory with the proper leadership and companions, such a student will have many times as many useful ideas as he can himself possibly follow up with research. Hardly any one who has completed advanced work in a science can read, say an abstract journal, without thinking of many problems which he would like to investigate. Fertility of mind is not so much an inborn quality of the mind itself as of the training and association which that mind has had.

The ideal industrial research organization may perhaps be outlined with a knowledge of its development during the last fifteen years. I shall give, frankly, my personal views in the matter, based on an intimate knowledge of four universities, three professional research laboratories and a visiting acquaintance, so to speak, with quite a number of others. The ideal industrial laboratory, in my mind, consists of two quite distinct divisions: one taking the brunt of works troubles and testing or making analyses of the material used. The other wing is complementary to this and deals with the larger fundamental problems encountered, problems requiring skilled specialists and considerable time for their solution. The alternative organization with a single research laboratory covering both works troubles and fundamental problems is not so successful. The plan in this case is to have considerable research in progress of very little interest to the company, but engaging a staff much larger than required to take care of ordinary works troubles. In this case, when works troubles are many and insistent, as they are wont to be at times, the staff engaged upon fundamental research forms a reserve to be called out occasionally to deal with works troubles. The disadvantages of this are that the fundamental work is subject to more or less frequent interruption and can not be so efficiently carried on. On the other hand, when the research is in two quite distinct divisions, fundamental work is not subject to interruption by works troubles.

Industrial research is preeminently fitted to be carried on by team work. This we have developed to a high degree in Pittsburgh and consider very much more efficient than the alternative cell system where each leading man has a room or suite of rooms to himself and keeps his work to himself. In the ideal organization, two or three men work together on the same large problem or group of problems, the aim being to have a good theoretical man and a good experimentalist working together as much as possible or even a physicist and chemist in some cases. The characteristic of the team work plan, however, is the conference system. The five or six men most interested in each line of research meet for an hour each week to discuss the problem in its various aspects, to plan new work and to consider various interpretations and applications of the results obtained. The ideal conference is not less than four and not more than eight men and includes an efficient stenographer. To one experienced in such team work, the results of getting together are surprising. A good suggestion is no sooner made than capped by a better and the saving in time and effort is almost incalculable.

The conference system also aids in putting useful results before the other wing of the research division and before the patent department. At each of our conferences are representatives of the other wing of the research division, charged with taking up any results immediately applicable, and a member of the legal department who takes care of any ideas worth patenting. This plan of conferences relieves the scientific men from responsibility for calling the attention of the works or of the patent department to useful patentable results.

So far as national welfare is concerned, in order to increase our stock of organized knowledge, we need more teaching by professors and instructors in closer touch with industrial problems. So far as developing research men goes, the ideal instructor is probably an ex-professional research man and, in many cases, one who has made a reputation or a fortune by his work along industrial lines. Another need is, of course, more research laboratories all along the line. The increase would naturally be among industrial organizations and the expense borne largely by manufacturing concerns, since it is they who reap the chief direct financial benefit.

Another great need is cooperation among the various branches of research: university, national and industrial. There should be a free interchange of men between such laboratories, and each should be thoroughly familiar with the needs and problems of the other. One great benefit from this war, if it lasts sufficiently long, will be to force cooperation between different branches of research.

III. *The Application of Organized Knowledge.*—The present national crisis brings home to us the crying needs of the nation in availing itself of the knowledge and ability at its command. Fifty thousand specialists in applying scientific knowledge to practical problems as well as scores of research laboratories have offered their services to the nation. But problems requiring investigation are slow in being developed. Once they are formulated and given to the engineers of the country, few will remain unsolved very long.

It is for the engineer to apply the results of research to practical problems and to carry practical problems demanding general research back to the research laboratories. To the engineer, every special problem requires a special application of fundamental principles. Is it too much to hope that the day is rapidly approaching when all great problems, particularly those of our national and state governments, will be automatically placed in the hands of trained specialists? Not self-seeking politicians, nor yet men with mere theories, but engineers with a real command of fundamental principles, men with an unbroken record of big achievements and no failures, men ever ready to stake their all on their ability to handle problems in their specialty.

Professor Joseph Le Conte, in an address years ago, remarked that each of the great professions first attained high standing when it was taught as such in universities. When so taught, the professional men turned out are no longer quacks, but each has a real command of the fundamental principles in his chosen field of action. The basic relation is that any profession has standing in so far as its fundamental principles have been developed and applied. To retain standing, a profession must be continually increasing its stock of knowledge of fundamental principles through research. The engineer of standing in his profession must not be content with a mere working knowledge of rules of thumb, but must have a real command of basic principles in his chosen field and in related fields. The illuminating engineer, for example, should know not only lighting, but should possess a working knowledge of the laws of vision and of geometrical and physical optics. So the great physician or construction engineer has a command of his own field and an intimate acquaintance with related fields.

So also with research as a profession, the leaders have not only a taste for research and logical minds to clearly analyze and attack problems with thorough scientific knowledge, but have a knowledge of the principles of research; getting the most out of their own minds, avoiding side issues, cooperating with their colleageus and putting their most valuable results in permanent, readily available form. Research is one of the youngest of the professions and one with a promising future, but let no one enter it without thorough knowledge or a full understanding of its aims and methods. With sufficient attention given to research and to its application, this nation with its great national resources should at once attain and retain a permanent lead among the nations of the earth.

P. G. Nutting

THE PROOF OF MICROBIAL AGENCY IN THE CHEMICAL TRANSFORMATIONS OF SOIL

Every now and then in the development of a science it is well to stop and consider how many of the current statements are based on established fact and how many have arisen from assumptions repeated so often that they have come to be generally believed. Certain common statements in regard to the bacteriology of soil may well bear such scrutiny. Has it, for instance, been definitely proved that any particular microorganisms cause any of the well-known biological activities in soil? This question is quite pertinent at present because of statements frequently found in the literature that certain bacteria or groups of bacteria are responsible for certain chemical transformations in soil, although complete proof of the causal relation has never been obtained.

The cause of these loose statements is easy to understand when it is considered that it is practically impossible to obtain direct evidence as to what actually goes on within the soil. Laboratory experiments show what the microorganisms do under laboratory conditions, but not what they do in the soil. Even though the activity of an organism be tested in soil itself, its true activity in the field may still remain unknown, because such laboratory tests have to be carried out in pure culture, and pure cultures do not occur in the field. The activities of bacteria in soil are associ-