WHAT CONSTITUTES EFFICIENCY IN RESEARCH?¹

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In selecting this subject I realized that it was not a new one, and that nearly everything that could be said on the topic had already been said in one way or another. If I had known then as well as I know now how very much had been said, how many presidential addresses on the organization of science fill the pages of *Science*, I think that I would have had compassion and spared my audience this last straw. And yet, in going through these numerous addresses and letters, I cannot help thinking that in some cases the writers have failed to distinguish between the real organization and the defects of the organization, between the meaning of the word "efficiency" as used in business, and what constitutes efficiency in research. I use the words "organization" and "efficiency" deliberately, realizing fully the extent to which they have been overworked and the antipathy which they arouse in the minds of some efficient directors of well organized laboratories.

One does not need to read many pages of the journals in which scientists exchange ideas to realize how many look upon an organization as applied to research as something in part, if not wholly, evil. For them the word "organization" is associated with supervision, with administrative duties, with everything that is the antithesis of the freedom of thought and action assumed to be essential to real research.

We are frequently reminded that many of the great men of science have worked alone and the inference is drawn that their accomplishment was great because they were unhampered by

¹ Address of the President at the Twenty-fourth annual meeting of the Society of American Bacteriologists, Detroit, Michigan, December, 1922.

an organization. Someone has painted an amusing picture of Newton ordered by the director of a modern organization to make a progress report on his theory of gravitation. There seems to be a fear in some quarters that if one is truly scientific he cannot be "efficient." This aversion to efficiency has no doubt been accentuated by the association of the word in the past few years with a systematized effort to increase the output of machines and manual labor. From this we have come to associate the word "efficiency" with stopwatch studies, with close supervision, with time cards, and with detailed daily reports. Organization and efficiency remind us of the proposal, seriously made during the war by a prominent American, for a research institution surrounded by a high brick wall and manned by a force of scientists working in eight-hour shifts. We are afraid that in an effort to increase our efficiency, our freedom of working out our problems in our own way, and at our own convenience will be curtailed.

It must be admitted that some of the fears incited by the word organization have a basis in fact. It is true that many of our ablest investigators have ceased to be producers through the encroachment of administrative duties incident to a growing organization. The preëminent scientists of the past—the Newtons, Darwins and Pasteurs were not forced to pay this penalty for proved ability, and continued to be producing investigators throughout their lives. We can estimate now what the world would probably have lost if these men had been obliged to devote the greater part of their energies to administrative work. If Pasteur had been the director of a modern laboratory, preparing reports and estimates, attending meetings of committees and research councils, speaking at dinners and women's clubs, would his name have become so interwoven with our daily life that its use may be taken as a measure of the state of civilization of a people? But little can be proved one way or the other by what did happen, or what might have happened to the Newtons and Pasteurs; they were extraordinary men and would have risen above the distracting influences of an organization just as they rose above the lack of material equipment.

Certain evils have become so associated in our minds with a large organization that we are inclined to look on these evils as inherent and unavoidable. Red tape is not confined exclusively to the business of the government, but may be found entangling the work and impeding progress in any large organization. It is safe to say that the greatest difficulties which the average investigator has to overcome are not involved in his problem itself, but are those thrown in his way by man-made organizations. Usually these obstacles are constructed in the name of efficiency and by those who are employed to assist, not to obstruct.

I could cite from my own experience many instances which illustrate how a highly complex organization frequently defeats the end for which it was created and these, no doubt, could be matched by any one connected with any large institution. In the course of an investigation to which a vacuum pump was essential the shaft of the pump was broken. Now, an inefficient scientist, unhampered by a highly organized supply system, would have sent a messenger to the nearest hardware shop for 2 feet of 1-inch steel and in a few hours the machinist could have made a new shaft; but a purchasing committee which, by its own confession, is highly efficient, had protected the financial interests of the government by contracting with a dealer in Pittsburgh, for a year's supply of this particular kind and size of steel. Consequently, it became necessary to make a formal request for a requisition on this dealer, a process which in the normal course of events requires several days, and then to wait the pleasure of the dealer in filling this large order. Fortunately, in this case, the purchasing committee had not foreseen the possibility of needing parts for this particular kind of pump and we had the privilege of ordering a new shaft from the manufacturer. By using the telegraph it was possible to reduce the delay to a few days.

Many of the complications of organization have resulted from the application of the popular fallacy that efficiency and economy can be promoted by the consolidation of small units into larger ones. One of the inherent evils of a large organization is the tendency of the clerical element to dominate the scientific force. As the organization grows the worker becomes further removed

from the source of authority, the paths through which the business of the organization must pass become devious and full of obstacles, and the hands of the worker become tied by regulations and precedents. The economy of consolidation is also more frequently apparent than real. If the function of a library is merely to distribute books at the least possible expense, no doubt this end could be best accomplished in a centralized library, but it is better to appear extravagant by spending money for branch libraries than to have a laboratory force work for weeks or months on a problem because, through difficulty in getting books and periodicals, they are ignorant of the fact that the problem has been solved.

One of the windmills against which the organizers most frequently tilt is the duplication of work. It is easy to see that in certain types of work duplication does become a great evil, but in research work it is not duplication but the lack of duplication that is to be avoided. Few investigations lead to wholly correct conclusions and new results become established as facts only when they are confirmed by several workers. It is only by the cumulative effect of disconnected attacks on a problem from different angles that progress is made. This may be true even in a single laboratory in so far as it involves application of different types of mind to the same problem.

Evidently the evil of which the writers of the presidential addresses stand in greatest fear is a curtailment of the investigator's inherent right to develop his own ideas in his way.

Dr. A. Franklin Shull (1), speaking of ways of discouraging or limiting freedom of research says that "one of these ways is the appointment of an investigator to a position for the purpose of studying a certain problem." He cites a terrible example where this actually occurred and adds, "By the terms of his appointment his energy could be directed into other channels only with the permission of his superior officer. Such direction from above could be justified only in the case of an assistant or an investigator on temporary appointment, not in the case of a permanent colleague."

I must confess to many transgressions along exactly this line, and for my peace of mind would like to have someone tell me how the very definite problems which confront us can be solved without thus limiting freedom of research. The money with which the investigator's salary is paid, and his equipment purchased, may have been provided for the study of a very definite question and it does not seem unreasonable to expect him to stick to his last. The particular method by which he attempts to solve the problem is another question, but even here many beginners are unfortunate in having had too much freedom. Some men are successful only because, throughout their career, a skilful pilot has held them to the course.

William Morton Wheeler (2) after a very entertaining description of the characteristics and habits of the genus scientific investigator, concludes that "Attempts at organizing investigators must fail because their highly specialized activities depend to such a great extent on their peculiar native aptitudes or capacities."

While I must admit some evidence of temperament, my experience has led me to believe that investigators do not differ in their essential characteristics from other people.

It is true that the qualities which make a successful investigator are different from those which make a successful salesman, or financier, or mechanic, but are we ready to admit that they preclude the possibilities of systemization or coöperation?

However, the trend of the presidential addresses is not entirely toward individualism as opposed to organization. Milliken (3) says, "The extraordinary rapidity with which scientific developments were made during the war was unquestionably due then, first, to the forming of these highly competent research groups; and, second, to the establishment of effective channels for the coöperation between these groups."

This process of organization and coöperation, while greatly stimulated by war conditions, is not an especially new movement.

Less than a quarter of a century has seen the development of great institutions with resources, equipment and organization undreamed of by our fathers. We have voluntarily formed what

has been described as a "superorganization of superorganizers," the National Research Council. We are told that we must coöperate. The efficiency of existing organizations is to be increased by coördination and consolidation. The problem of organization is continually with us whether we welcome it or not. No laboratory is so small as to avoid it. When an investigator acquires an assistant it comes to him. When a man becomes an assistant he faces an organization problem and his is, perhaps, the more difficult one because he lacks the authority to put his ideas into effect.

In building up our organization there are certain obvious ends to be gained and certain obvious evils to be avoided. We perfect our organization to obtain efficiency. Our funds are usually provided for definite purposes. We have a program of work planned, a particular end to attain, and the money available should be so expended that it will carry us the greatest possible distance on the road to that end. Of even greater importance is the necessity of expending the energy and ability of the workers so that they will yield the greatest returns in the advancement of human knowledge.

The danger in any organization of scientific work lies in the tendency to submerge the individuality of the worker. In such organization we are not dealing with machines, nor with piece workers. In research work the unit of the organization is a highly developed human mind. The product which our organization turns out is the result of the thought of an individual worker, and just so far as the organization inhibits or distracts these minds from their true course it is inefficient. On the other hand, the organization promotes efficiency so far as it tends to permit and to stimulate originality and freedom of thought in the individual worker and at the same time to coördinate and concentrate the activities of the several investigators on the particular problem in hand.

In considering means of attaining this end we must keep in mind the distinction between the methods of the factory efficiency engineer and those which must prevail in the laboratory. In the factory the road to efficiency leads through system, routine,

supervision, coördination of men and machines, office records and elimination of unnecessary motions. In the laboratory efficiency is obtained by reducing supervision to the lowest point compatible with the ability of the investigator; by removing him from the distractions of report writing and routine office work; by surrounding him with an atmosphere conducive to study and meditation; by providing him with the special equipment necessary to the solution of his problem and by promoting a spirit of coöperation which will unite the individual investigators into a compact body working together on a single group of problems. We should always keep in mind that the staff is the laboratory not the building or the equipment which are frequently exhibited as examples of a great laboratory. Liebig is said to have done some of his best work in a kitchen; Pasteur, working in a dark basement was directing a great laboratory.

However, in building our organization on the individual worker we must keep in mind that there are diverse kinds and conditions of men. Scientific investigators may be divided into two classes, the leaders and the followers. By "followers" I intend no disparagement of the great class of scientists to which most of us belong. Indeed, it would be very difficult to decide which is of the greatest value. Daniel Boone and his fellow explorers who blazed the way through the mountains and the pathless forests into the Kentucky valleys made a great state possible but without the settlers who followed in their footsteps and turned the wilderness into productive farms and thriving cities their efforts would have been valueless and forgotten.

The leaders are the exceptional men, with imagination, who have the faculty of grasping the significance of phenomena that to the ordinary worker seem trivial or incomprehensible, and who, by a series of brilliantly planned experiments, push back a little further the wall of darkness that marks the limit of human knowledge. For a man of this type the organization must afford wide latitude in the selection of problems and in the method of solving them. On the other hand, there are many men who, if left to the dictates of their own imagination, flit from one unfinished project to another and accomplish little beyond their

own entertainment, while they may, under the right leadership, become good investigators. For these men a more rigid project system is necessary. For the great majority of investigators who depend for their progress on industry, perseverance and logical thinking all that is necessary is the essential equipment and an opportunity to develop their particular problem.

In developing an organization consideration must also be given to the type of work to be done, although the underlying principles apply to all cases. The only real difference in research institutions is in the primary object to be gained. Is the institution designed to produce investigators or the results of investigation? Each will train men and each will increase knowledge, but the organization and methods of work will necessarily be along different lines. The classification into laboratories for pure science as contrasted with applied or industrial laboratories is not basic but merely indicates the scope of the laboratory. In the laboratory of pure science knowledge is sought for knowledge's sake. The laboratory is in a way incomplete, a fragment of a laboratory. The investigator, through inclination, lack of facilities or appreciation of the possible application of his results fails to carry his investigation to the point at which the value is evident.

In the words of Huxley "What people call applied science is nothing but the application of pure science to particular classes of problems." The applied laboratory which does not develop its own problems in pure science must begin where others have left off and carry the investigation on to its application. The more highly organized of the industrial laboratories have provided for what we will continue to call, for lack of a better term, pure science, wisely permitting great latitude in the selection and development of problems. The wisdom of this course is already evident in the fundamental results of great scientific and economic value which have come from some of the investigations of these laboratories. No one can foretell the results of investigations of this nature or estimate their value, not even their pecuniary value to the company which profits by the investigation. The history of the progress of science in the past teaches us that the great

discoveries of the future, will be along lines which cannot be conceived in advance. Discoveries, which to the ordinary layman are the creatures of a single master mind, are the natural sequences of a long series of investigations. They are not isolated points, but the apexes of pyramids shining in the sun of publicity. Few, if any, of these investigations were undertaken with even a hope that their application would benefit humanity. The invaluable x-ray was only an incidental result in a series of investigations on the nature of the electric discharge. These studies were made possible by the perfection of methods of obtaining high vacua and this in turn was developed to permit the determination of the atomic weight of thallium. The public knows of the "discovery" of x-rays, but is not interested in the nature of the electric discharge and knows, and cares, nothing about the atomic weight of thallium.

The research laboratories of the universities are usually organized on a somewhat different basis from the industrial laboratory in that the main function is teaching and the results of research are incidental. The limitation of many of the investigators both in time and experience, and the necessity of selecting problems which will give training in research to successive generations of students, narrow the scope and determine very largely the nature of the organization.

In an industrial laboratory, while there is frequently necessity for training new men, the organization is based entirely on research for the sake of the results.

A complete research organization has four functions: (a) The study and development of new laws and fundamental truths without regard to their application or usefulness; (b) the development of possible uses for new knowledge, and the solution of problems which arise in the varied activities of mankind; (c) the trial of results obtained in the laboratory under conditions which will test their applicability to practice; (d) the dissemination of the results obtained. Few organizations are complete in this sense. Some confine themselves to the study of fundamental science only; some build on the basic facts developed by others; few have the facilities for applying what they learn under working conditions.

It is very easy to make diagrams on paper showing how, in a logical way, this should be done, but diagrams, no matter how well done, cannot really represent human beings, and as Mr. Little has observed, "There is danger in an organization chart—danger that it may be mistaken for the organization." Whatever type of organization is chosen, the executive functions will center about the administrative head of the institution. We are in the habit of designating this official as a director, although the term does not fit harmoniously with our conception of scientific research. The motive power for research must come from within and it can be directed only in a very limited way. The head of a research organization must be, not a director but a leader. His function is not so much to direct research as to recruit a staff; to provide the necessary material equipment; to maintain an atmosphere conducive to constant application, and to coördinate the work of the investigators on the problems of the laboratory. The members of the staff are his associates, not his assistants, and he serves the ends of science best when he stands between them and the distractions of correspondence, finances, and report writing.

The form of organization which has been most used in the past follows the lines of the basic sciences. This requires departments of chemistry, bacteriology, pathology, or whatever sciences may be involved. It necessitates arrangement for coöperation between departments on any problem involving more than one science, something which is very easy to show in a diagram, but very difficult to obtain in practice. This system has the advantage of making it possible to have an especially strong man responsible for the work in each branch of science, but carried to its logical end establishes artificial barriers which impede progress.

In the early days of the Department of Agriculture there was a Division of Microscopy where, presumably, all of the microscopic work was to be done. The fallacy of this arrangement was, apparently, early recognized, but there grew up later the Bureau of Chemistry, which was to do all of the chemical work for the Department. The difficulties of an organization which confined all of the work in a basic science to one laboratory were not so

evident but when different bureaus, in order to make progress on their problems, found it necessary to establish chemical laboratories this arrangement was abandoned in its turn. Such an arrangement is illogical in a small laboratory, and becomes more and more illogical as the organization grows larger. In solving a biological problem chemistry must be looked on only as a means to the end, a yard stick by which the investigator measures and explains the changes which he observes. The chemical work should be under his control as completely as any of the other tools essential to the solution of his problem.

The organization which usually evolves, if a laboratory grows up naturally, is a force of workers with various qualifications grouped around each problem. A chart showing an organization on this plan usually develops into a fine collection of wheels within wheels. In practice, however, it does not work out as simply as the diagram would indicate. The nature of the plan requires a continual shifting and readjustment of men as the problem develops, or is completed, or abandoned, and new problems are taken up.

It is not always feasible to assign an old and more experienced investigator to work under a younger man who may be responsible for a problem. Some excellent investigators do not have the knack of managing assistants; others do not work well independently, but require close supervision.

The organization around the problem becomes then a question of fitting the arrangement to the workers available, deciding each case on the basis of its own peculiar conditions. It is entirely possible to obtain in one laboratory harmonious and efficient work with the various problems organized in different ways; in one with workers of more or less independence of action responsible to a leader who is in turn responsible to the director; in others with independent workers coöperating and each responsible to the director for his part.

A minor but essential part of the laboratory is that which deals with what may be called the accessory branches, through which the material needs of the organization are provided. These are not coördinate with the investigational staff, but are service units existing only to expedite the work of the investigators.

A general in planning a campaign provides means of transportation, and lines of communication to keep his troops supplied with ammunition. This branch of the service is secondary, but of the most vital importance. If it fails the campaign fails. Its function is to get ammunition to the fighting troops in sufficient quantities and at the time it is needed. The color of the wagons in which it is brought is of little importance. It is of little comfort after the battle is lost for want of shells to know that the records of the ordinance division are complete and accurate.

The clerical force of a research organization performs a similar function. Its function is not to establish channels through which the business of the laboratory must go regardless of consequences, but to provide ways of getting the ammunition to the front when it is needed. The office that has allowed a blind adherence to records and regulation to obscure this end has outlived its usefulness.

The method of administering this service is a difficult one to arrange satisfactorily. Some of the large research institutions relieve the director of all responsibility for financial matters, making the accounting and purchasing division responsible directly to the governing board. Some go to the other extreme, and not only make the clerical force responsible to the director of the laboratory, but place it under the immediate direction of a man of scientific training. The former method would seem to offer large opportunity for the exaggerated idea of the importance and authority which is the great evil of the service branches—the latter should enable the director to make the clerical force what it should be, a servant to the investigational work.

What has been said of the clerical force applies also to the library service, except that with few exceptions the librarians appreciate their relation to the investigational staff and any failure to function properly is usually due to faulty organization rather than to lack of inclination to be of assistance. The contact between the staff and the library must necessarily be a close one. Nothing is more essential to efficiency in research than ready access to the literature. Library administration is not clerical work, but requires special training, a knowledge of

languages, of methods of classification, and above all a wide acquaintance with scientific literature. The library should not be controlled in any way by the clerical force, nor should it be responsible to any particular branch of the laboratory. Its contact with the force should be through the director. It should be so organized that the periodicals are available promptly and the library staff should be in a position to be of real assistance in searching the literature.

A third auxiliary branch which should not be overlooked is the mechanical shop. Even in these days there are scientists whose time is more valuable than that of mechanics and it is not economy to allow work to wait for special apparatus or repairs. In a small laboratory the shop may be only a well equipped work bench; in some lines of investigation the shop is really part of the laboratory, and should be complete and adequately manned. A day rarely passes in a laboratory that some small construction or repair job does not arise. The mechanical branch should be available to take care of this work without unreasonable delay.

Although the results of research are of no immediate value unless an application can be shown, few laboratories outside of the industrial institutions have any organization for the specific purpose of applying new facts and theories to practice. It does not necessarily follow that results are lost because no special provision is made for their utilization, but it is no doubt true that many valuable results are overlooked, and forgotten, because the investigation could not be carried to its logical conclusion.

If Mendel, instead of being an example of the highly individualistic type of investigator, had been a part of a modern research organization, the basic law which he discovered would not have been buried for years, but would have been put into practice at once to the great advancement of plant and animal breeding. Some investigators do not continue their investigations when they reach the applied stage because their tastes lead them to new paths in unexplored fields. In other cases the necessary equipment may not be available, or the branch of human activity to which the results may apply not at hand. The equipment needed may be a factory, a farm, a water system, or a hospital. The

expense and in some investigations the danger to human life may be so great that it becomes advisable to follow the laboratory study with larger but still limited and controlled experiments.

This is generally recognized in industrial laboratories where provision is usually made for carrying an investigation through the laboratory, through a miniature factory test and finally through a full scale factory operation.

In bacteriological work the same course is frequently followed, although the analogy may not be evident at first glance. The soil bacteriologist has his pots and experimental plots, the pathologist his animal rooms and hospital wards.

The efficiency of many other lines of investigation would be greatly increased if definite provisions could be made for carrying investigations to real completion without unnecessary delay. While in some cases it is real economy to encourage an investigator to turn to new problems of a basic nature, leaving the application of his results to others, as a rule the man who develops new principles is the one best fitted by interest and knowledge of the subject to apply them.

Many processes which work well in the laboratory develop defects when tried on a large scale. Many new methods of real value have never gotten beyond this stage, because there was no one with sufficient interest or technical knowledge to adapt the process to the new conditions. Thus there is a great economic loss which can be overcome by proper organization.

And, finally, to complete the work it is necessary to carry the results to that part of the public which is directly concerned. Is the task completed when a technical paper is published in a scientific journal? If its value lies in its use in investigational work it is usually sufficient to make it available to other scientists but if it is something which affects established practices it is only a beginning. The inertia of public opinion cannot be overcome so easily. Even the medical profession, accustomed as it is to rapid advance, cannot always be reached by the printed word alone. New developments in agricultural science permeate very slowly through the journals, the text books, and the teachers to the farms.

The necessity for actual demonstration has become more fully realized, particularly since progress in all fields of science has become so rapid that practice lags behind. The medical profession was convinced of the value of typhoid vaccination by large scale demonstration in the army. The efficiency of administration in introducing new methods in agriculture is now generally recognized and practiced. There is, however, too often a lack of continuity between the investigation and the demonstration. The investigator lacks the facilities for demonstrating his new methods, and the demonstrator is not always sufficiently familiar with the investigational work to select the most valuable results or to avoid mistakes and failures. Real efficiency is obtained when an investigation can go direct from the laboratory to the demonstration stage, with sufficient control retained by the laboratory to insure the use of correct methods.

In the laboratory with which I am connected, if you will pardon the personal allusion, an organization has been perfected which makes this possible. I may cite as an illustration the case of a bacteriological study which proved the relation of certain types of bacteria to the production of the characteristic flavor in Swiss cheese. Through coöperation with a technical man the value of these bacteria in cheese making was determined by miniature factory tests in the laboratory. While this demonstration was very successful, if the work had been stopped at this stage it would still be in the "of scientific interest, but doubtful applicability" class. Everyone who has had experience with pure cultures in the industries knows that there is a wide gulf between the propagation of cultures by a bacteriologist in a laboratory, and by a hand in a factory. Preliminary trials in factories proved that the use of these cheese cultures was no exception. Accordingly, some years were given to operations on a commercial scale in a factory controlled by the laboratory. This not only served to develop and correct some of the difficulties which occur under factory conditions, but also demonstrated the commercial value of the cultures and incidentally trained men for field work.

The actual introduction of these methods into the industry was passed on to another section of the organization, with sufficient control of the methods retained by the laboratory to insure their correct application. The method of introduction consists in demonstration in the factory of the value of the cultures and instruction to the operators in their use.

Thus, we have an example of an organization which provides for basic investigation, for laboratory scale manufacturing tests, for trials under controlled commercial conditions, and finally for carrying the results to the industry by demonstrations and instruction.

If I should attempt to summarize these rambling observations in one sentence I would say that in promoting efficiency in research the essential thing is not the form of the organization but rather the spirit in which it is applied. The organization should be like a roadway over which the investigation passes, not a structure in which it is confined.

Wheeler, from whose address I have already quoted says: "And as the surface of the planet becomes more and more densely covered with its human population, it becomes increasingly necessary to retain portions of it in a wild state, i.e., free from the organizing mania of man, as national and city parks or reservations to which we can escape during our holidays from the administrators, organizers and efficiency experts and everything they stand for, and return to a nature that really understands the business of organization."

Dr. Wheeler has used a more apt illustration perhaps than he realized. The parks to which he would escape to allow his primordial instincts free play are possible only through an efficient organization. The forest through which he roams unhindered has been saved from commercial exploitation by this organization; a fire warden in some isolated lookout station is watching for the first sign of the conflagration which his primitive instinct may have started, and a carefully organized and equipped fire-fighting force is waiting for the telephone message saying that its services are needed at a certain spot; this organization stocks the streams with fish, protects the game, and constructs

roads and trails over which he can flee from the dreaded organizer; in short, it makes it possible for him to escape, as he expresses it, "from the organized routine of our existence."

This conception of a park fits so well with my idea of a properly organized laboratory that I can say with Gratiano, "I thank thee for teaching me that word."

In the ideal research organization the investigator can follow the lure of his elusive problem protected from the distractions of business and finance and propaganda: he can make better progress and enjoy it none the less because the paths have been made smooth and the camp grounds supplied with wood and water. A sense of security should come from the knowledge that a well organized system is protecting him from the consuming conflagration. He may even find it pleasant to exchange notes with the watcher when his path leads him to the look-out station which connects him with the outer world.

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