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SCIENCE AND CIVILIZATION[1]

IF we go no farther than the dictionary, "science" implies organized knowledge, while "civilization" implies those arts and practices which pertain to a community life. But a community life, whether from the viewpoint of the clan, the village, the city, the state, the nation or the community of nations, implies specialization and cooperation. It means that one individual or group of individuals shall devote, in a restrictive way, time and human effort to the performance of some one task in an expert or specially effective way. And thus, with many individuals or groups of individuals, many tasks are undertaken, many things are accomplished and all go as contributions into the great pool of human product, and from which each individual or group of individuals, in return for its own contribution, draws the varied elements of life and comfort.

As we approach a more and more fully objective view of our world as it now is—a view and judgment as by our distant cousins on Mars—we shall perhaps see more and more clearly that the entire fabric of our present civilization is based on this reciprocal relation of give and take, like some vast chemical reaction which is ever proceeding toward some ultimate condition of equilibrium, but to which it will perhaps never attain. There is, then, this great pool of the product of human effort. Each individual, by contributing in some relatively expert fashion the product of his own effort, time and energy to this pool, becomes entitled thereby to draw therefrom such portion of the products of his fellows as he may need or as his own contribution may merit.

And furthermore, a wide range of the most serious problems of our civilization center about the ways and means of effecting this exchange and interchange. How as individuals may the farmer, the miner, the mechanic, the tradesman, the banker, the professional man, place most efficiently each his own contribution in this great pool and draw therefrom those contributions of others, needful and reasonably sufficient for life and comfort?

It was not always thus. There was a time in the evolution of man, when the individual, or at most the

[1] Address given at the Mills College meeting of the Pacific Division of the American Association for the Advancement of Science, June 18, 1896.

family, was the unit and was of necessity sufficient unto itself. There came a time, however, when man set his foot on the gradient leading toward our modern condition; and that was perhaps in the days of our paleolithic ancestors, when some one man began to develop an especial skill in the forming of flint arrow or spear heads, or when some one acquired special aptitude in the weaving of crude basketry or in the making of the rough early forms of pottery and earthenware. Just so soon as special skill or aptitude becomes set apart for the doing of some one of the things needful for life, just at that point do we find the foundation of barter and exchange and of the cooperative scheme of life which we have developed to such vast complexity in our own days.

But progress in civilization, conditioned upon the exercise of special skill or aptitude, implies a field for the exercise of such specialized human effort. This is, of course, the whole domain of nature in her various manifestations in the form of matter and of energy—if we care to still retain the distinction between these two concepts of our objective world.

The products of the earth and the energies of nature have thus furnished the field wherein has been exercised the specialized efforts of man, and the products of which have constituted this ever-swelling reservoir from which the elements of civilization have been drawn.

But all this must obviously require an acquaintanceship with nature and with her so-called laws—more, it must require a working partnership with her and clearly, as our acquaintanceship is the more extended and our partnership the more sympathetic, so will our work with her be the more effective—so will our great reservoir the more widely extend its borders and so may our individual draughts from it be deeper, fuller and richer.

And again, in order that the progress made by one individual or by one generation may not be lost to those which follow, there must be an organized record of this entire body of our understandings with nature; only by such record can progress be made continuous; only thus can such understanding be made to constitute a gradually accumulating and expanding integration of its divergent and discrete elements.

But what is science but an acquaintanceship with nature, and what is our organized record of science but the expression of the terms of our partnership with her?

If, then, we ask of the relation between science and civilization, the question answers itself. If civilization is a result of our gradually improving utilization of nature's products and energies through a more and more effective partnership with her, and if science is the organized body of our understandings and agreements with nature, the two are seen as inseparable parts of one whole. There could be no civilization without science—and, given a body of science with rational beings, a civilization must result.

At this point, perhaps, a word may be in order as to the two phases of science known under the broad terms of fundamental and applied. In so far as the distinction is valid, the emphasis in the former is placed on the extension of the boundaries of our acquaintance with nature—on adding to the sum of our organized knowledge; while in the latter, the emphasis rests on the application of such knowledge to some specific end in the service of humanity. Actually, the two are inextricably interwoven. The prosecution of problems in fundamental science can not, in general, be carried on without the means—apparatus, equipment, etc.—provided through activities in applied science. It is not, perhaps, going too far to say that, in general, the whole domain of research in fundamental science, and with special reference to experimental research, calls upon the entire organized domain of applied science for its material ways and means. On the other hand, applied science is continually asking aid of fundamental science in the solution of special problems which arise in connection with the realization of specific ends. The two are bound together as inseparable parts of one whole. Neither alone can meet the full requirements for human progress. Both are fundamentally essential. However, in so far as there is a distinction to be drawn between these phases of scientific work, the American Association for the Advancement of Science is an aggregation of those in whose work the primary emphasis is more commonly placed on fundamental rather than on applied science and our thoughts this evening will the more properly focus themselves on the relations of so-called fundamental science to civilization.

I shall not take the time to attempt to recite any catalogue of scientific achievements which have borne fruit as expressed in essential elements of our modern civilization, nor, on the other hand, any list of such elements which trace back to sources in fundamental science. To do so in any even reasonable degree would be to catalogue, on the one hand, hundreds or even thousands of achievements in the various domains of fundamental science and on the other, to list substantially the entire material content of our modern civilization.

It will be in order, however, to deal in broad terms with the special place which fundamental science occupies in our scheme of civilization. Thus, as we have seen, the worker in this field is concerned primarily with enlarging the boundaries of our knowledge, noting new observations of fact, discovering new laws,

new relations, with linking up terminal facts or elements of science with certain basic elements or concepts, such as space, time, matter, energy, electrons, protons, quanta, an ether, etc.—and all independent of special thought as to how these particular items are to be built into the fabric of our civilization. But is it not evident that this product of labor in fields of fundamental science furnishes the material for the fabrication of the fundamental building blocks out of which the structure of our civilization must be reared. With a body of science comprising a few isolated facts of nature we can postulate a civilization of the order of the paleolithic or even the neolithic stages of culture. With some further extension of the boundaries of our acquaintance with nature, we may postulate a civilization represented by the kitchen middens or the lake dwellers; with something further, we have a foundation for the civilizations of the pre-Homeric and earliest Egyptian ages; and so on, as the body of fundamental science enlarges so may we find foundation on which to erect the ever-expanding material content of human civilization.

It is, of course, only necessary to note in passing that in these earlier stages of the evolution of our civilization there was nothing which could be called science in the sense of an organized body of knowledge regarding nature. Nevertheless, there was a more or less indefinite body of empirical knowledge. The paleolithic stone chipper knew the properties of his flint and how, cunningly, to apply pressure or impact in such way as to produce the forms desired—an empirical knowledge combined with a manual skill which produced, at its culmination, products which for beauty of form and finish have never been since excelled, if indeed equalled. In like manner the prehistoric potter knew the action of fire upon clay and the adaptabilities of various clays to his needs, and the basket weaver knew his osiers, reeds and grasses. Perhaps the most important single step made by man in his slow progress through the dawn stages of civilization was that which gave him an empirical knowledge of fire, its production, control and preservation, and its effect on various substances—in particular on those which he had learned to find available as food.

No form of what we call civilization is even thinkable without fire under control in the service of man and that ancient empirical scientist, brought down to our day through the Grecian legend of Prometheus, stands as the great prototype of those who in later years have so extended and deepened our observational acquaintance with nature.

But these early approaches toward an understanding with nature were halting, disconnected and imperfect in method, and the results realized were correspondingly inadequate as building blocks for an advancing civilization. For thousands upon thousands of years after these dawn stages there was little change—down through the centuries of the old stone age, the new stone age, the bronze age, and on to within the reach of recorded history, there was but slight change in the mode of approach toward this problem of improving our understandings with nature. Always there was a gradually growing total of empiric knowledge, but without organization or interpretation. Mention by name need only be made of the scientific systems, if we may so call them, of ancient civilizations—Babylonian, Persian, Egyptian, Phoenician, Grecian, Roman.

Only in recent times have we been able to develop and organize, in what we believe to be its most effective form, the grand strategy which determines our plan of operation in pushing ever more deeply into nature's mode of work and in associating ourselves more and more effectively with her. All of this has come about, largely since the days of Francis Bacon, and in consequence of the formula—observe, record, analyze, compare, relate, generalize, test, reject, and select.

However, to return to our main thesis, it is obvious that the body of organized knowledge which has, in this manner, been growing ever more rapidly in recent times, must form the building stones out of which, through adaptation to special ends, we may erect our structure of civilization. With scanty building material, so will our structure be mean and inadequate. With an arrest of the provision of new material, so correspondingly will our structure be limited; for while we may, perhaps, combine the elements which represent our present body of fundamental science into many new and as yet unknown applications to the needs of human life and progress, yet there must be a limit to the number of such combinations. If fundamental science should cease to grow from to-day forward, we might thus go on for a time with new combinations of old material. But the end of progress would soon come. We should find ourselves simply beating old straw or, to vary the figure, moving in closed orbits and without progress toward any vast unfolding purpose.

This leads to the first important point which I would make and that bears upon the responsibility which rests upon the great body of workers in fundamental science, with regard to the part which they are called upon to take in our progress as a race along an ascending gradient of civilization. The part is obviously that of pioneers. They are the vanguard; they must blaze the way, working always on the outposts and along the boundary line between the known and the unknown. They stand thus as the first line of contact between civilization on the one

hand and the vast areas of nature's unknown on the other. If they falter, so will the progress of civilization lag. As they push forward, so will civilization follow. Can there be conceived a position of larger opportunity or of graver responsibility?

But if the responsibility for the carrying on of faithful and effective work in fields of fundamental science rests thus weightily upon those who have chosen this as their field of work, the responsibility is not theirs alone. The prosecution of work in science requires two major factors, human time and effort, and material means. It can hardly be expected that those who have chosen this as their field of human effort can supply more than the first of these two components. Successful work in fields of science must depend upon an effective co-partnership between those who are able and willing to supply the human element and external sources of material support.

These external sources, it is clear that we must characterize as society at large; and primarily because society at large is the beneficiary of the work of the scientist. The past quarter century has witnessed a marvelous expansion in the material content of life and all tracing back ultimately to work in fields of fundamental and applied science.

In our daily routine of life we have come to look upon, as commonplace, facilities and privileges which a few years ago would have seemed beyond the reach of the imagination. Society is now demanding these as the routine elements of our daily round of life, and like Oliver Twist, is always calling for more. Whether all this is good for us as members of society, individually or collectively, is open to question. It does not follow that because we have more of facilities and privileges, based on the utilization of the materials and energies of nature, we are thereby any better, wiser or happier. These are qualities which spring from within rather than from without.

Indeed, the whole question of the responsibility for the use to which the products of the work of the scientist are put is one of the deepest interest, not only to the scientist himself but to society at large. The same scientific result, accordingly as it may be applied, may secure better and larger food crops or serve as an explosive agent carrying death and destruction in its wake. The same drug may be used to kill or to cure. The same vapor may be employed as an aid to the surgeon or to the midnight robber and murderer. The same implement may serve for protection or for aggression; the same chemical substance as a medicine or as a degrading drug; the same means of pleasure or recreation may be used for recuperation or for dissipation and waste. And so throughout the whole domain of our modern civilization, contributions made by the scientist may commonly enough be used, either wisely or foolishly. They may be used to build up or to destroy. Whose the responsibility?

Surely the scientist in the exercise of his function as such should not be held responsible for the use to which his discoveries are put by society at large. This must rest rather upon society, at least in so far as we can conceive of responsibility as attaching to so vast and inchoate a body. Society is, however, made up of individuals and responsibility may rest upon an individual. And so, as an individual member of society, the scientist must accept his own share of this responsibility.

There are some, in modern days, who go so far as to fear that the modern developments of science—the material content of this modern scientific age—may after all prove to be a Frankenstein which will, in the end, bring about the undoing of our present civilization and the closure of another great cycle in the round of human progress. I am not of these, but it must be admitted that the situation is not without its possible menace, and as a member of society at large, the scientist has a clear duty in standing for a policy in the application of the results of his own work, actively in opposition to those tendencies which make for the sapping of moral and spiritual fiber.

However, in the exercise of his own functions as such, the scientist may be reassured by the reflection that, whatever may be the possibilities of misuse, nevertheless every advance in our acquaintanceship with nature and every improvement in the terms of our partnership with her does carry with it at least some potential improvement in the external conditions of life and the possible turning of another leaf in the great book within which the mysteries of human evolution are slowly unfolding into, as we hope, a larger and a fuller life.

If then, to pick up our thread of thought, there is a duty on the part of the scientist to carry on, so is there a reciprocal duty on the part of society, as the potential beneficiary, to furnish the one element which the scientist can not himself provide—at least normally in adequate degree—and that is, material support.

Coming nearer home and looking over own own vast national domain from ocean to ocean and from our northern borders to the Gulf, with our prosperity and progress during the past quarter or half century, have we as a people recognized in sufficient degree the extent to which this progress is based on advances in fundamental science? My own answer is no. We have devoted and are devoting large sums and munificent support to varied fields of applied science, but this is working with the materials which we now

have; it is carrying to fruition past labors in fundamental science; it is not adding new materials or the possibility of new combinations. I would not be understood as in any degree overlooking or minimizing the splendid work which *is* being done in our midst in fields of fundamental science, but only as urging that, in proportion to the extent to which our prosperity and progress are due to work in fundamental science and in proportion to the support which is accorded to work in applied science, we as a people should give a larger support to work of basic and fundamental character.

One of the cardinal principles of our industrial policy has been stated to be that of rapid turnover and quick returns. It may well be that, as a people, we are thinking too much of quick return in the present and too little of a foundation for continuing returns in the future. The American genius is said to be essentially practical, by which we may imply the special emphasis which we are prone to place on realizing early and definite returns on our investments and among such, early and definite returns on our investments in science and scientific effort.

But there is another and higher mode of expression for the practical instinct—a mode which takes account of the future as well as of the present, a mode which reckons with world movements rather than with those within our own borders, a mode the significance of which we can only gain by standing, in spirit, outside these movements on the checkerboard of life and from some distant point viewing the individual moves only as component parts of an intricate and slowly unfolding scheme.

If we as a people could but gain this objective viewpoint, we should realize the vital necessity of being practical through consistent, continued and adequate support of those activities in science which have for their purpose the extension of the borders of our knowledge and the addition of new building blocks for incorporation into the material structure of our civilization.

Passing from questions of responsibility and of material ways and means for carrying on work in fundamental science, let us turn to another topic bearing upon the question of efficiency within the working force of scientists themselves.

Following the trend of evolution in all phases of civilization, scientists have found it necessary to specialize more and more narrowly as the great aggregate of scientific knowledge accumulates. It thus results that the modern man of science, due to limitations of memory, of time and of aptitude, can have personal and effective knowledge of but the smallest portion of the vast domain which science now covers. It has been said that Leibnitz was the last to hold, within the domain of one mind, the learning of his day. Even if this be so, the world's work must now be carried on by the great army of us who can lay no claim to the mental endowments of Leibnitz, and even if we could, or even if he were of to-day rather than of the seventeenth century, surely no such claim could be made at the present time. The accumulation of learning, merely in the sense of the acquisition of information and its record, has become, in recent years, so enormous as to result, in a very real sense, in an embarrassment of riches.

It is true that we are served, in the study of problems in science, with a marvelous mental endowment—an endowment which gives to us at will hundreds or thousands of memory impressions bearing directly or indirectly upon the matter upon which our attention is focussed. The explanation for some phenomenon is sought. The mind sends out feelers seeking similarities or dissimilarities with other phenomena, or ties linking back the facts of observation to known and accepted elements in the great body of science. And if we are able to establish such ties or links, we say that the phenomenon is explained. In all this how admirably are we served by this endowment and how utterly helpless should we be without the aid of memory and some sense of analysis, comparison and an appreciation of resemblances and differences? But marvelous as this all is, the capacity of any one mind for dealing with one of nature's problems is, after all, subject to the limitations incident to our present stage of human evolution.

But the phenomena of nature recognize no such limitations nor do they recognize the arbitrary system of pigeonholes in which we are wont to classify our activities and store their product. Thus in the investigation of any phenomenon of nature, any other phenomenon may be significant. Any so-called law or principle or mode of action developed in one domain of science, may have some pertinent bearing in another, no matter in how apparently widely separated a domain of activity it may seem to lie.

We may be morally sure that in the domain of mathematics, for example, there are now stored away in archives, transactions and proceedings, various results, relations, principles, methods of analysis, all of which might be given useful and fruitful application in other domains of science—in physics, in chemistry, in biology, in economics, statistics, etc.—if only we could bring into the same focus in one mind the problem and the means of treatment. And the same is true with regard to physics and chemistry, for example, in relation to problems in the field of biology, geology and astronomy, and throughout the domain of applied science. But in order that the biologist, for example, concerned with some specific problem in his own field,

should be able at first hand to command all the potential resources of science at large, he must either have first-hand knowledge of the resources available in mathematics, physics, chemistry, etc., or be able to draft information from these domains, applicable to his particular problem. The first is quite beyond the capacity of the single human mind, limited as we are in time, memory and aptitude, and we have thus far developed no effective way of realizing the second.

The heart of the problem is how to bring about, in one domain of science, the application of results developed in other domains, and in particular in view of the fact that in general only small and isolated portions of any one domain can be brought sharply to focus in any one mind at any one time.

This, to my mind, is one of the most important problems pressing upon those working in the broad domain of science. Results are unquestionably now at hand in one domain and awaiting effective application in other domains—how shall we bring about some more effective measure of relief for this condition?

There is need for the organization of some superscience—some science of the use of science which shall aid in our efforts to bring into a common focus results from separate and seemingly unrelated areas of this broad domain.

There seems to be no solution ready to hand for this problem. It must come as a result of study and effort, and there will always be human limitations beyond which we can not hope to pass. Some beginning has been made in the form of organized abstracts and their publication. But this is only a beginning. Something more than an abstract is often wanted—something rather in the nature of an interpretation of a result in one domain of science into a form which may be readily grasped by those dealing with problems in other fields. Either this or else more and more must we depend on the services of those rare individuals who are able to grasp some considerable part of more than one domain of science and thus bring into focus in one mind the scattered elements of one ramifying problem. Or otherwise, we may perhaps find partial solutions in the cooperative work of two, three or four minds, representing each some special field of endeavor and concentrating directly on some one complex problem. Thus we may suppose a mathematician, a physicist, a chemist and a botanist to concentrate directly and with undivided purpose upon some one problem in the field of the latter. We do not necessarily see what part each might contribute, but it is more than probable that, in regard to such a biological problem, there might be realized a concentration of resource which would carry the problem definitely farther toward solution than through the efforts of the botanist alone. This is, in a sense, an effort to bring the content of four minds into a single focus upon a single problem.

These are only suggestions of some avenues of approach to this problem. Other avenues must be found and to an increasing degree must we give attention to this problem of the organization of a science of the use of science if we are to attempt to make effective use of the vast and ever-accumulating store of scientific information which has already reached such stupendous proportions and which is growing at an ever-increasing rate.

If among these thoughts regarding the relation of science to civilization there is any one point upon which I would wish to place some special emphasis, it is that of the responsibility of the body of workers in fundamental science, collectively and individually, charged as they are with the exercise of one of the great functions, vitally significant in and absolutely essential to the progress of civilization. I have already referred to this at an earlier point. Its importance, not only to us as scientists, but to society at large, may perhaps justify some further reference developed from a slightly different mode of approach.

Can we, in mental vision, disassociate ourselves from the stream of human progress and thus gain some measurably objective view of this vast scheme of evolution, of which we normally see ourselves only as participants? Can we climb to some high mountain peak and thence, looking over far horizons, gain some better orientation of ourselves and of our own work in reference to the great world efforts and movements about us?

As we may be able to reach some such viewpoint, we shall surely gain a clearer vision of our own place in the slowly unrolling scheme of human affairs and a sense of proportion which should enable us the better to align our own efforts with those of our fellow workers in other fields of human activity.

In any event, and as I have at an earlier point noted, we should in some such manner obtain a clearer vision of what we call our civilization, as a vast cooperative enterprise—an enterprise of which the individual elements are carried on by those assumed to be specially skilled in that particular element. At least such is the ideal. Now among those elements, each corresponding to the exercise of some one function, there are a certain number which relate to the bare necessities of existence. Thus we must have food, clothing and shelter and there must be those who provide for these basic organic needs. Then on a later level in evolutionary time, we have developed a vast array of activities, catering first to the category of luxuries but which rapidly become transformed to that of necessities—at least in our own estimation.

Thus, and only by way of illustration, means have been provided permitting us to gratify our desire for travel, far and near, over land and water and through the air, and with ever-increasing speed and comfort; or again, means have been given us responsive to our urge to communicate with our fellow, whether a neighbor or a dweller in the antipodes, and with the spoken voice or the written word and with the practical annihilation of time. Again, means wherewith to send our own produce to markets far and near over the earth's surface and to draw on the whole world's produce for our own convenience and comfort. And there have been provided as well all the complicated agencies and means suited to secure the needed degree of regulation in human conduct in a society so interdependent in its elements as has ours become; functions again needed to cater to our sense of the esthetic —to that urge to pass beyond the merely utilitarian to that which appeals to the sense of the beautiful; functions needed to meet our urge toward amusement, sport, relaxation; functions multiple in number and often interlinked in character and in exercise.

And how has the civilization of our caveman forebears or of Homeric days or of medieval times become so marvelously transformed into that of our own day? There has been one central effective means and that is the transmission by racial inheritance of the elements of the civilization of one generation to the next following. Biological inheritance provides for the transmission of biological characters, but there is a larger sense in which we may view inheritance—a sense in which the generation, the nation or the race is the individual unit and in which we view the transmission of knowledge, of achievement, of culture, from one generation to the next, as a process broadly parallel to that of the transmission of bodily or personal characteristics from parent to children. In a racial sense each generation is the child of that which precedes and we may have a racial heredity and a racial transmission of culture, of learning and of the integrated elements of civilization.

It is true that with racial inheritance through the ages, the gradient of progress has not been always continuous or uniform. At times there has seemed to be regression rather than progression. Advance has been made in periodic movements, perhaps at the moment not always forward and upward, but in the large and viewed in distant perspective, always with an ultimate gain, always with a net upward and onward trend and always again as the expression of racial inheritance.

But this implies something to inherit, and what is more, a widening field of choice over which the material to be passed on may be chosen. Progress does not depend so much upon the continuous transmission, without discard, of a gradually accumulating store of learning, culture and achievement, as upon the conscious and intelligent selection, over an ever-widening field of choice, of those elements best suited to the environment of the moment or to the racial demands of the time. In this way, progress implies examination, comparison, test, discard and selection, and exercised over this ever-widening field of choice. But who shall provide the ever-widening field of choice? Here indeed is the function of the worker in fundamental science. His the duty and the privilege to provide the basic material which shall give to civilization this ever-widening horizon of selection and which shall make possible the transmission to the coming generation—already interpenetrating with our own—some increment in quantity and some improvement in quality, of those elements which shall furnish the material basis for the civilization of which they are to be the exponents.

The obligation of the worker in these fields seems clear—it is an obligation which may be viewed collectively or individually. In no case can we escape it. The remainder of humanity are standing aside, as it were, and are waiting upon our performance of this particular function. This is our contribution to that great pool of the products of human effort. Without this particular contribution, the progress of civilization must falter and cease.

Whether individually or collectively, we may view our passage through life as that of a comet coming from afar, remaining for a time a member of our system and then passing on, whither we may not know. So we journey between two unknowns and are given but a short day in which to perform our allotted task. Like the comet from the depths of space, we pass this way but once.

W. F. DURAND

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BACTERIA AND THE ORIGIN OF SPECIES

THERE is, perhaps, no field of research that has borne such an abundant harvest in recent years as the study of bacteria. While micro-organisms have been investigated from many points of view and in relation to many and diverse activities, the intimate relationship of pathogenic or disease-producing microbes to human happiness and welfare appears to have blinded not only the popular, but also the scientific mind to the broader significance of bacteria in the world.

Not many years ago we were orthodoxically taught that the atom is the indivisible unit of matter. Today we are amazed to learn of the tremendous com-