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THE STIMULATION OF RESEARCH IN PURE SCIENCE WHICH HAS RESULTED FROM THE NEEDS OF ENGINEERS AND OF INDUSTRY[1]

THE appreciation of pure science in all civilized countries has steadily increased over an indefinitely long period, but it is quite common to look back to Roger Bacon, or to printing presses, or to Francis Bacon, or to some other definite point whence the start seems to have been made. I doubt if any one time can be chosen over another. The first living cell which made new motions concluded as definitely and acted as consistently as a result of its experiments as we do. We are still infinitely removed from complete appreciation, and therefore not far from the amoeba. The laws illustrated by the amoeba tell us that there are good, bad and indifferent activities, that countless promising experiments may be made, that we may learn after the experiment whether we are better or worse off and finally that the habit of experimenting, or the character of curiosity, may be perpetuated, just as all existing types of plant and animal have been perpetuated.

But to shorten the story I start with Francis Bacon and then proceed at once to the Invisible College of England, about 1645. In 1662 this became the Royal Society for Improving Natural Knowledge, and it has been improving it ever since. Thousands of other groups of scientists and engineers, aiming to advance civilization, have cooperated to the same end. Certainly leading minds long ago recognized research in science as the proper means of human advancement and amelioration.

Gradually in each country accumulating appreciation of knowledge doubtless determined the increasing growth of organized experimental research in schools and universities. This in turn plainly acted on the growing industries, and a closer and closer cooperation became effective. Thus from a time when the monasteries were the schools and students cloistered monks, the old countries became ever more alert to the value of science in human affairs, and college-training put men into service, through the professions or the industries. These in turn still further pro-

[1] Address before the Section of Engineering, American Association for the Advancement of Science, Philadelphia, December 29, 1926.

moted the idea of advancement of learning. Cambridge (England), in my own day, revolutionized pure physical science, and Cambridge (America) enjoyed its first scientist college president.

Strangely enough, it has always resulted that the most remote observations, the most unusual experiments, the most unexpected phenomena, the most insignificant new facts and the most unnecessary discoveries developed into subsequent needs and necessities, but the needs have not usually pointed ahead towards new discoveries. It is becoming more and more clear that the limits of advancement of man are in his own head and hands, and only realized through a process of appreciating nature.

It is a minor, but noteworthy, fact, that in recent years industries in all countries have taken part in scientific work and employed on the whole a rapidly increasing number of engineers and scientists. Interest in new knowledge is no longer confined to the universities. And while it is true that there has been a recognized division of labor such that colleges and universities have usually done pioneer work, and industrial engineers have usually expanded or developed new truths for general appreciation or consumption, it is also true that to-day one may find in the world's scientific literature about as many publications of general scientific value from industrial laboratories, state and private laboratories as from colleges and universities. It is becoming the deliberate habit of industries to support the sciences on which they are based. Perhaps the most marked case in our country, and certainly one which deserves honorable mention, is the telephone company. Its publications are numerous, highly scientific and equal in every way to those of the foremost physical societies. All this betokens a healthy attitude, but no better than we ought to expect from intelligent people who have the history of the past in mind.

I was asked to consider research in pure science with reference to the contributions it receives from industry. I don't intend, in fact I could not, distinguish in that way, though I made an attempt. What I am saying is a natural development of an attempt to divide or locate scientific research either as to quality or source, and I conclude by still more highly appreciating the science of schools and the contributions of engineers and industries.

All research in science seems good to me, and artificial distinctions as to kind and source are invidious. Research will be extended because people see more and more clearly how it works. Pure research is merely uncovering parts of infinite stores whose value, often appreciated, is never anticipated. From my subject you would expect me to deal with pure research and the animation which necessity gives it, but pure science research is not so animated. So I have to clarify the field with definitions, and I accept the recent classification of Balls (*Nature,* August 28, 1926). I will not repeat the eight (a to h) classes, but, beginning with so-called "pure" research, I accept his idea that it is typified by university research, and that it has three degrees of freedom; *i.e.,* freedom in method, aim and subject. Six other classes are defined which carry all the other combinations of freedom and finally class (h) is reached. In this there is *no* degree of freedom, and it is represented by "testing" and "works control laboratory work." Since I accept these definitions I can not attribute pure science research to definite external causes. It is due to internal inquisitiveness of individuals. We may imagine, if we wish, that all scientific work is done because of future needs, but if we use the term "pure science" at all, then we should thank Mr. Balls for classifying the research types, however stimulated. He has given us terms to include all so-called impure and applied research.

Type "a" interests us most. The prime stimulus of this scientific research is curiosity. The most important function of colleges and universities is appreciating inquisitiveness and educating curiosity. There is often a tendency to train men for predetermined mechanical work in which perhaps only the teacher feels the mental stimulus. This is intellectual myopia.

As Mr. Balls gives us eight classes we can probably place any given research in some one of them.

Industry and its engineers call for a great deal of new or more accurate data (classes b to g of Balls). Some of it is splendid material for engineering students. It teaches them careful manipulation and helps introduce them to their chosen fields. But it may be so ill used as to habituate one in seeking only the anticipated object of his forced or hurried work. This makes him bridle or even kill his curiosity, and may train him only as a thoughtless automaton. For example, steel, usually used cold, is now being used hot, and we need strength-tests at high temperatures. Is this research in pure science? It is free in method, but not in subject nor aim. Having that one degree of freedom, it is type "d" of the Balls scale. Under such classification one may suggest that it is the duty of the industry to look out for "d" as it always does for class "h," for example.

A quarter century's experience with existing varieties of research, from pure academic, with three degrees of freedom, to "trouble shooting," with no freedom at all, I see that neither I nor any one else completely comprehends research. This is very fortunate, because we may still learn something about it—by research. I might waste your time by facetiously recognizing only two types, useful and useless. But there can be no such division in fact. I was asked to point out the stimulation of research in pure science which has resulted from the needs of engineers and of industry. I feel helpless, inquisitive and speculative. Does it work that way? Engineers generally do not want pure research, though they want it to have been done. Perhaps one could *call* this stimulation. They frequently ask for things which are clearly definable but non-existent. For engineering, things must be tangible and contingent. Engineers have pressing problems to solve, and the words "pure research" as a cure for their immediate wants usually connote only postponement or disappointment. Pure research, to be good, is usually random (beyond the edge of knowledge), and is mainly activated inquisitiveness. Engineers never call the products of such research "necessities" until after the engineering event. Every good engineer is too perpetually busy to be much attracted by what is called pure research, however well he may know its laws of birth and heredity. It is productive, but it is not production.

There *is* a stimulation of pure research which doubtless, deep down in the tendencies of research men, is a natural development of the sense for general survival and of amelioration. Most of the so-called pure research that I know about, however, seems to have been at the time as remote from engineering as human effort could make it, and certainly it was not visibly stimulated by recognized needs of engineering. To my mind, engineering is using material knowledge with safety for our convenience. The more knowledge available the better. The more accurate it is, the safer we are. Therefore, whether the individual research man may feel it or not, he is working for future engineers. In that way, pure research is certainly stimulated by engineering.

In geographical discovery there is an obvious parallel. The pioneer, a sport, sportsman or a mere trapper, takes all sorts of risks, travels with difficulty through all kinds of unknown territory, sets various traps or fishes for whatever bites. When he returns to civilization he trades off his catch and his new knowledge. No engineering was in his mind. A real woods pioneer might keep still if he realized that by describing a certain waterfall he was insuring its early development. He would not promote a power site nor a nature-destroying hamlet. But, nevertheless, the pioneer is unconsciously part of the continually growing thing which we call civilization.

The three-degree research man is much like this pioneer. He is usually not weighing the needs of engineers, but rather making the discoveries which interest him. Commercial uses of his discoveries seem often uninteresting, and sometimes even distasteful to him. For example, a pure research man, studying the parasites or the life habits of some lowly insect, makes it possible for an entomological engineer later to save the apple crop of Australia by importing there the enemy of the destructive aphis.

This principle of random research, call it the blind principle, if you will, is evident everywhere—in radio, for example. When crystal sets were the key to receiving stations, engineering needed improvements in efficiency, increases in range and reduction of cost. Engineering refinements of iron filings, cats' whiskers and special synthetic crystals were soon exhausted. But pure research had already disclosed knowledge which made vacuum tubes a promising new territory. Without the random inquisitive research in vacuum phenomena, extending all the way from Edison's early experiments through Thomson, Richardson, Fleming, De Forest, Langmuir and many others, radio might more logically have sought its engineering advances in the saps of trees or in ectoplasm than in a vacuum.

To my mind, the wonderful trait of inquisitiveness in man has thus far kept so much ahead of recognized needs (that is, of engineering) that unapplied assets can still be tapped for further amelioration. As this has been a law from the time when the amoeba first started to move, I think encouraged curiosity is the safest criterion of an improving civilization. If we assumed that man should research only when he felt the need of a definite thing, he would continually butt his empty head against a wall and always the wrong wall.

As J. J. Thomson has said, "Discoveries are not terminals, but avenues." They are not places to stop, but ways to proceed, and the more there are, the more new ones may be opened. The more we subtract from the unknown the greater and more useful it becomes.

Our ancestors who engineered the explored west recognized few of our present needs. Canal boats or ox teams, slowly advancing to fertile lands, were recognized needs, and home-grown food and home-made clothes were necessities. The grandchildren need mile-a-minute transportation, with simultaneous diner and sleeper luxuries. They demand the discoveries in food, raiment, comforts and news from everywhere, integrated over all time. The earlier conception of needs extended to a little faster packet boat, a little heavier oxen, deeper furrows, bigger farms and a longer workday. Similarly, we in our turn blindly think we conceive the needful. Just as changes resulting from curiosity and research have made us forget the needs for canal boats, oxen and even twelve-hour days, so probably our descendants will find more in creation than we do to-day.

Chemical engineers, anticipating needs for liquid fuels, exhaust the known methods of production. Research chemists, perhaps ignorant of fuels, inquisitively study laboratory curiosities, like catalysis, or they test the correctness of new mathematics, like the Helmholtz and Nernst equations, the Le Chatelier principle, or the kinetic gas theory. They thus store shelves with principles and data which later become indispensable.

An inquisitive engineer, stimulated by the need of change, tries one of these novelties, and soon we hear of synthetic oils and alcohol. The same scientific researches which guide engineering in one such field usually serve many others.

In refrigerating engineering, for example, the history of ammonia, of sulphur dioxide, of methyl chloride or of butane does not disclose stimulation of the engineers' needs. These four avenues proceed ninety degrees apart, and only crossed where the refrigerating engineer happened to read the names of the avenues. Had he been a fertilizer engineer, for example, he might have called new knowledge of ammonia a necessity, but scarcely that of sulphur dioxide.

Engineers are busy with things like buildings, bridges, automobiles, locomotives, subways, power plants, railways, pipe lines and aeroplanes. Each became a necessity only after it had been discovered, reproduced and tested. It wasn't a perfectly obvious thing to build the first bridge. No engineer needed it. A tree fell across a creek and some inquisitive animal shinned over. This first bridge research resembles much of pure research, a kind of monkeying, but it is more useful than aping, as Robinson has pointed out. So also many inquisitive fellows burned their fingers at natural fires long before any one thought of controlling heat or making artificial fires. Some curiosity-seeker later produced hand-made fire, just as inquisitive men, from Nero to Watt, played with steam.

Obviously, it is wrong to overlook the enormous stimulation due to cooperation between research and industry or the mutual relationship of researcher and engineer. I am only contending against the thought that any one can long foresee what may become our major needs and thereby circumscribe pure science research. None of our necessities were planned that way, not even a wheel. Wheels came into engineering, as steam did, through curiosity. Electricity came into engineering after years of accumulated and recorded inquisitiveness, including Faraday's work. Chemistry was the plaything of magicians, monks and pure-science teachers centuries before chemical engineering became a comprehensible term.

As there is no end to new knowledge, so engineering must always grow. Every engineer looks longingly at the properties he employs, to see if they can not be extended, and this leads to endless research of direct utility. But if pure science has any meaning, this is not it. A reason for saying so is that I fear we Americans may grow scientifically near-sighted. We may mistakenly think education the mere recording or measurement of things. The mechanical operations may submerge the mental, and minds be shut in instead of opened out. Transportation was not advanced by breeding fast horses. Trimming sails did not lead to their displacement by steam. The telephone came without improving voices, and radio has come without improving wires. Aeronautics comes more nearly through curiosity over explosions than through feathers. We seem to get ahead by uncovering lightly covered creations rather than by stretching what we know further than it will go.

University-trained men who find themselves in industrial work are not naturally divorced from their earlier scientific associates, nor do they cease to take interest in pure science. Engineering thereby increasingly contributes to science, and industries cooperate with educational institutions. The president of a corporation need be no less interested in pure science than a science teacher. The one may enjoy his method of contribution as well as the other. It would indeed be difficult to differentiate between the cooperate efforts of a Kodak Park or a Nela Park laboratory, as shown by their scientific publications, and an equal volume of pure science publications from colleges. It may be unusual to attribute the same kind of interest in science to the officers of the respective institutions. It exists, however, and indicates the unity of motive which all educated people possess.

We advance more often by finding in nature what we are permitted to use than by making or forcing there what we think we want, so there are the different classes of research. The unhampered, pure science seems best fitted for universities. Though called random research it is neither casual nor accidental. It is the most natural activity of the good teacher in every science. His field is expanding, and he will teach better if he knows its enclosing forests and takes part in their clearing. He needs no better guide than his inquiring mind. The research *engineer,* on the other hand, has some specific aim. Having entered a field already revealed by class "a" research, he plows straight furrows and stops only to remove obstructions. Thereby he also uncovers new knowledge, but he is not free to wander. If gold or coal lies beneath the rock disturbed by his plow, he may find it, but research men, using three degrees of freedom, are more apt to discover there everything but farm products. One aims directly to produce, the other to learn, and both are absolutely necessary to our advance. There is a natural pressure in competition to encourage the industrial needs, but only an intelligent foresight can insure pure, orderly research, because curiosity is usually restrained. These are generalities, and fortunately every subject and every man is complex. So it is that contributions also come from engineering needs. For example, electrons are discovered, their uses become needs. Pure science research is followed by the seven other classes. Electron emission of tungsten is made useful in radio and the phenomenon of electron emission is studied as broadly and freely as possible. Other elements, like thorium, are thus brought into radio service. The theoretical conceptions and mathematical conclusions are published by men in the industry and the advance of the science and the art accelerated. This process is relatively complete in electrical engineering, but much less so in other research fields. It is clear that every item of new knowledge of electricity can probably be made to do service somewhere. It is relatively a new, compact, orderly, but unlimited field. Research in it would not be so pure, so unattached, so remote as not to fit a use. Close cooperation is to be expected in it between its detached pioneers in colleges and those who plow and reap elsewhere, and a single scientist may do much of each.

Mechanical engineering is in a similar position and chemical engineering is rapidly reaching it. Biology, heredity, psychology, on the other hand—in fact, the greater number of sciences—still lack engineering cooperation. Through pure research there will certainly be continually made other as needful and yet unexpected disclosures as those we now enjoy, and perhaps in entomology, for example, there are more interesting possibilities than were seen in all physics before electricity was pioneered out of it by Faraday.

Bacon said of the Greeks that they had no antiquity of knowledge and no knowledge of antiquity. We see now how well they used what they had. But we ourselves have an accumulation of experimental facts of all kinds which, since the discovery of printing and the establishment of national and international scientific societies, has never ceased expanding. It is upon this stock of tested experience that engineering usually draws. The stimulation responsible for that stock is primarily natural curiosity and must be developed in education. The asset of engineering is exact knowledge. The valuable attributes of research men are conscious ignorance and active curiosity. For an engineer "safety first" is a good slogan, but "safety last" is better for the man of research.

H. E. Armstrong said, "The pursuit of science is necessarily an *anti*-human practice, as it involves an all but impossible self-abnegation." It is more nearly an ante-human practice, as it first discloses to human ken created supplies not otherwise humanly available.

Curiosity may be limited, but creation is unlimited. Free or untrammeled research has given engineering far greater bequests than could be suggested by needs or preconceptions. As this reaction is more in evidence now than ever before, it will continue, and our first interest is to encourage the educated engineering mind. The obvious or pressing needs of industry can be relatively easily and safely cared for as at present.

We ought to realize that there may be a more valuable use of knowledge and truth than commercial developments, and by aiming at the full appreciation of creation we may do more than simply conquer and control our local environment. Perhaps industrial uses of new knowledge are after all only by-products or ways for advancing to something better. As Anatole France said, "The present is being built on the foundation of the wisdom of the past and is destined for the use of the future."

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PHYSIOLOGY AT THE NAPLES STATION

THE most significant effort since the reorganization of the Stazione Zoologica is to be found in the development of the physiological division. Specific leadership, so effective in other departments of the laboratory, was happily provided for in January, 1926, by the appointment of Dr. Sereni as resident physiologist. Since then there has been added to the permanent staff as custodian of apparatus an expert instrument maker whose time is devoted to repairs and renovations of the older equipment; to keeping the new in running order and to such constructions *de novo* as may be called for from time to time by the investigators.

In its historical aspects, this physiological renaissance is not without interest. Among the qualities that made Anton Dohrn a great leader was his ability to foresee. Although a systematist and morphologist by predilection, personal interests did not prevent him from realizing where, in the future, biology was likely to make its most active growth. The very first addition to the original plant was intended to foster the earlier steps in comparative and general physiology. Fourteen years later additional space and facilities for physiology became available by the construction of a wing chiefly for pure and physiological chemistry. The first impression made by the total array of large and small laboratories, private rooms, dark chambers, etc., is well preserved in Boveri's Ge-