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PURE SCIENCE AND ENGINEERING[1]

A GENERATION ago the physicist felt himself to be a very superior sort of person indeed. If he were called upon to address an audience, as I am to-day, made up largely of engineers, he had to make a conscious effort not to appear condescending. He knew, and was very conscious of his knowledge, that *his* quest for scientific truth was a finer and more altruistic thing than the engineer's search for a useful application of a principle. There were a number of sure guiding principles which he had discovered: law of this, conservation of that and the principle of the other thing. By the end of the last century the physicist was becoming a bit dogmatic and certainly in no apparent danger of acquiring an inferiority complex. To-day, all this is changed, at least for all of us except the very few of the brilliant young men who are courageously tackling what we are coming to feel is about the most elusive and capricious thing in all nature—the atom.

During the past twenty-five years dogma generally, and scientific dogma in particular, has grown unfashionable, and we physicists have become as a class singularly free from cock-sureness and perhaps rather too humble when we consider the wealth of important discoveries which have come as by-products in our as yet unsuccessful attempts to understand the nature and behavior of the atom.

We feel much more sympathetic to the biologist than we did; our troubles with inanimate matter make us realize better what difficulties he is confronted with, deprived as he is of the aid of the higher mathematics which has been of such great help to us. We feel a need as never before of aid from the engineer, for research in atomic physics is requiring ever more powerful accessories such as only the engineers can furnish us.

We are glad therefore to recall tactfully the debt which engineering owes to former and present research workers in the pure sciences and to enlist your intelligent interest in the solution of what appears to be for pure and applied science alike the most fundamental problem—the constitution of the atom.

[1] Address given on the occasion of the opening of the Engineering Building of Princeton University, November 15, 1928.

We are glad to acknowledge at the same time our debt to you, and we would remind you that we too are engineers, or at least descendants of engineers.

Engineering is the response of science to the practical needs of the day, and research beyond the known is first of all necessary and then is prosecuted for its own sake. The demand for the application of what *was* known has invariably preceded the study of the subject for its own sake and we are merely further advanced in this necessary evolution than you are. The demand for application to medicine created the science of chemistry. Archimedes, to mention only one of the founders of mechanics, appears to have been working on a definite practical problem when he discovered the principle which bears his name.

Astronomy certainly grew out of the needs, practical in its day, of astrology, while later in England under the Stuarts the first astronomical observatory was founded for the practical needs of a sea-faring nation.

This growth of the pure sciences in response to the practical needs of the time is shown in the history of the oldest universities: Bologna before 1118 began as a law school; Salerno, 1231, as a school of medicine; Paris, twelfth century, as a theological seminary; Montpellier, 1190, as a school of medical jurisprudence. Later in our own country all the colleges founded before 1826 (University of Virginia) were in reality training schools for the clergy or for lawyers.

The first universities to offer a *studium generale* were Toulouse and Orleans in the first half of the thirteenth century, and it was in these and the many universities founded in Europe in the succeeding centuries that the dictum of Aristotle, "the universal pursuit of utility is far from becoming to magnanimous and free spirits," acted to exclude the pure sciences from the curricula. If our modern universities have acted in a stepmotherly fashion towards engineering and other professional studies until a way was found of including these subjects in separate schools or colleges, the treatment of the pure sciences by the mediëval university was still harsher, for they were excluded entirely from fellowship with the seven subjects which constituted the liberal arts. The trivium and quadrivium of the earlier universities were likened to the seven columns of the House of Wisdom, spoken of in the Book of Proverbs. Dante likened them to the seven celestial spheres, and placed grammar in the humble sphere of the moon, arithmetic in the more exalted sphere of the sun and astrology in the outermost of the seven spheres; a place was found for philosophy still more exalted in the empyrean.

It was no easy matter for science or indeed for any new subject to break into good university society—a society which regarded itself not only as the depository of all scholastic wisdom, but even as divinely ordained and constituted in seven and only seven branches.

Modern science had to organize itself outside the university: in England through the Royal Society; in France in part through the Institut de France and in part in the Muséum and the Collège de France. It was only when the universities were reorganized under separate faculties that pure science became an integral part of the university in most European countries and in the United States.

With regard to engineering and other applied sciences the general practice in the United States has been to admit them to equal administrative standing with the other schools or faculties which constitute the modern university. In European countries which have ministries of public instruction the practice has been to constitute schools of engineering, agriculture, and the like, administratively under the ministry, but nearly, or entirely, divorced from the state-supported university. It is of course inconsistent to include within the university faculties of applied science such as medicine and pharmacy, and professional schools such as law, and to exclude schools of engineering and agriculture, but most European universities prefer to be inconsistent rather than depart from the tradition of the Four Faculties first introduced into Paris in the Middle Ages.

The American practice has in its favor the keeping together in one administrative unit the faculties of pure and of applied sciences. This should and doubtless does keep down administrative and instructional overhead expenses and provides the possibility for natural and helpful personal contacts between the technical man and his more theoretical colleague.

One minor weakness of our system is that there are drawn into the enrolment of a technical school many students who are not destined for a technical career, nor indeed capable of entering it, but who have prepared themselves along lines which permit their admission to the technical school but would debar them from admission to the colleges of the liberal arts or of science.

The task of the modern university is twofold: teaching and discovery, or some other creative work which will add to the sum total of the resources of civilization in its attainment of liberty and its pursuit of happiness. Its task of teaching is of itself twofold. The providing of a general cultural education for all qualified to enter its gates, and the providing of special technical training in some or all of the liberal professions. Society needs the cultured man of the world and man of affairs. It needs the best and even better in its learned professions, and it needs the discoveries or creative effort of the so-called research workers to enrich the material or spiritual life of the nation.

The modern university is at least organized in a manner to perform this task for society. It is a community of teachers and teacher-scholars. It is not like a tree or growing thing with branches smaller and less fundamentally important than trunk or roots; rather is it like a network of electrical high-tension power distribution, each member of which may supply most of its local needs but which is so tied up and cross-linked with all the other members that it may draw or give power as the loads shift. At one time the flow may have been from the chemistry power station towards that of engineering, but if chemical engineering not only teaches its trade but also experiments in its own field it may generate sufficient power to sustain an outward flow that may be available at some unexpected point in the network.

The modern university is organized for cooperative effort, and I personally welcome the inclusion within the cooperative body of any school, technical or professional, whose object is the betterment of the training of its graduates and the prosecution of research in the fields of its underlying principles or their applications to the fundamental problems of everyday life. These schools must exist somewhere, and it seems to me that they may be maintained at a high level of excellence more easily within than without the university.

In an address on the relation of engineering to pure science it seems to be unavoidable that I should touch on the debt which engineering owes to research in the fundamental sciences, notably physics and chemistry. It is a very hackneyed subject and one which does not tempt me to talk at length. Everybody admits that without the fundamental researches of Michael Faraday in electromagnetism the vastly important technical subject of electrical engineering would not exist to-day, and our lives would be the poorer without the convenience which electric power brings into our homes, not to speak of the indirect benefits we all have from the use of electricity. I suppose we physicists may feel a glow of pride when we reflect that all this is due to the fundamental discovery of one of our own great men, but after all who was there to make a fundamental discovery such as Faraday's if not a physicist? There were actually no electrical engineers. In a certain sense Faraday was the first electrical engineer, and his intellectual progeny have done marvelous things with his original discovery, and so Faraday belongs hardly more to us than to you. Again, without the theoretical work of Clark Maxwell and the experimental verification of it by Heinrich Hertz, and I believe also the experimental work of O. W. Richardson here at Princeton, physicists all, we should not have the not-unmixed blessings of the radio. However, we should see in this instance not a cause for complacent self-congratulation of the theoretical scientist, but rather a clear example of the benefits of cooperative endeavor of pure and applied science.

Chemistry as a quantitative science is hardly more than a hundred years old, and chemical engineering is now only a lusty infant who bids fair to outgrow his big electrical brother. Naturally industrial chemistry has leaned heavily on the pure science and it seems to me in Europe threatens to absorb entirely the organic branch. In this field as in electrical engineering the great industrial corporations are establishing pure research laboratories in addition to their prosecution of industrial research. This is a tribute to the value of fundamental research and an indication that it is felt by the leaders in these industries that our universities are producing the right kind of men but not enough of them. Besides these research workers in the pay of industry but whose work is not always directed towards industrial applications there is a new class of worker growing up among us—the engineer, chemist or physicist engaged in the industrial research laboratories—fellow workers with those in the shops but university bred and scientifically alert. Sir William Bragg, in his presidential address at the last meeting of the British Association, said:

> The primitive craftsman has been replaced by separate persons or groups who have slipped away from each other almost without our realizing the fact. In the most recent times the separation has become more obvious and more dangerous, and that is why in so many directions efforts are being made to stem it. Can it be that the workman has a part demanding little intelligence, merely the capacity to repeat? Can it be expedient that mere manipulation should be left in the shop, while design and imagination have gone into the drawing office and shut the door behind them? Can it be right that the factory directorate should not be in immediate contact with the vast body of scientific knowledge?

Sir William Bragg, who combines the rare gifts of the prolific research worker and the inspiring popularizer of physical science, the gift in the latter field of a Tyndall and in the former that of a Faraday, has called attention to the need for a new type of engineer and to his opportunities for usefulness—the man close to the workingman, but not over him, to see that standardized processes be carried out according to plan, but obviously searching for new and better methods of accomplishing the old tasks.

We have a right to be proud of what seems to me to have been the greatest achievement of the American engineers, at least in so far as it has affected the living conditions of the majority of our population. I refer to mass production and I realize that others than the American engineers have participated in building it up. Through its establishment in manufacturing processes generally we are able so to cut down waste that we can compete in foreign markets with the products of other countries where workingmen must accept a lower standard of living, and our present great national welfare is in large measure chargeable to our development of mass production. Other countries are beginning to copy our methods, and the phrase "Americanization of industry" is translated into every language of western Europe. In a recent long residence abroad I have heard or read the phrase more often than any other, not even excepting the familiar ones "since the war" or "because of the war."

Now mass production has perhaps been a blessing to us in providing the workingman with a high wage and a large variety of commodities at a reasonable cost and ministering to the necessities of many who except for it must have gone without conveniences which free them for creative effort of their own and a sane enjoyment of the good things of life. But mass production can only be a quiet and very profitable phase in our restless search for the new and the better. I have no doubt but that there was mass production of bows and arrows and arbalests about the time that gunpowder came into use. It would appear that Great Britain's present industrial difficulties are due to the fact that an earlier monopoly in certain trades, a sort of mass production of an earlier time, has been lost partly through inattention to the possibilities of scientific betterment of existing methods and partly through disinclination to write off as losses huge capital expenditures of an earlier generation and risk new capital in the hope of greater returns.

Applied science builds and destroys. In this country we are feeling the effects, perhaps only temporarily, of applied science the builder. Some countries have adopted methods similar to ours, or have frankly copied us and hope to beat us at our own game; others hesitate in fear of the political consequences of transplanting something wholly alien to their own age-old tradition.

We shall surely not be left to profit by our discovery of the benefits of mass production, and if we are not it will be to our pure and applied scientists we must look quite as much as to our laborers, organizers and legislators to preserve our high standard of living in the competition for foreign markets.

Already and for some time past it is the scientist or the engineer who by his discoveries or their application has more profoundly modified our habits than any other class of worker. The invention of the telephone has many-folded the efficiency of the business man and forced us all into the habit of making quick decisions. The motor has increased our possible radius of action at least tenfold and has utterly changed the conditions of life of our rural population. The cinema and the radio have provided new amusements for us so that we find less time for reading and study. There has been introduced through these agencies a more general diffusion of superficial information at a cost of the riper culture which comes from reading and study. Scientific knowledge and the application of some of the discoveries are advancing over a very wide front, and the direction or amount of its motion at any point can not be predicted and can not and should not be controlled. Any day discoveries and adaptations of these may be made which will more profoundly modify our habits than the passage of laws by legislators. Any day a discovery in organic chemistry may be made which will lead to the substitution of a synthetic product for a natural one and bring to the starvation point whole populations on the other side of the earth, or a biochemist may synthesize another rare organic compound that will check the ravages of some dread disease.

Scientific inquiry into cause and effect and engineering craftsmanship are making the conditions under which we live, and this is happening and must happen without there being any social plans, except as these may be formed after the event by the financier and the legislator. The Bishop of Ripon at the Leeds meeting of the British Association in 1927 voiced a fairly general feeling of apprehension when he pleaded for a ten years' holiday in scientific inquiry and invention in order to let the economic, political and ethical branches of knowledge catch up on a runaway science. The proposal of a holiday is impractical, but the methods which have done much to stimulate and encourage research work in the pure sciences might be applied more liberally in the political, economic, historical and ethical field than they are at present. Pure science has been fortunate in the past in disposing of funds for fellowships for a well-selected group of outstanding research students who have passed the stage of candidacy for any academic degree and have already shown promise in their published work.

A liberal expenditure of funds for fellowships in the humanities and the support of a well-considered plan for bringing some sort of system and order into the chaotic state brought about by haphazard legislation might do much to remove the possible menace to our civilization which the Bishop of Ripon, speaking for a large class, fears from our overstimulated science and invention.

Personally I do not fear that our civilization will destroy itself with the aid of its own misdirected inventions. I foresee that more and more the engineers and scientifically trained men will direct the great social activities of government and the large industrial corporations. Science has always recruited from the type of man whose search for truth has been dispassionate. The erudite and the intellectuals have led; the people, knowing the leaders to be disinterested, have followed, and the existing order has been changed by evolution rather than by revolution.

We, in the training schools of the engineer and the pure scientist, must see to it that we train men of this type to take ever more important part in the direction of the affairs of the nation, and we must also see to it that as we are able to raise the standards for entrance we demand a broader cultural foundation on which to build our special training and that we provide opportunities and incentive for further self-culture on the side of the humanities while students are receiving this special training. This may now seem like an impossible counsel of perfection, but competition for desired positions, which has hitherto not been acute, owing to our favored position as a young nation with large national resources, is sure to become greater. Ambitious youth will come to us better trained than at present and we can and must raise our standards of admission and enhance the value of what we have to offer in general and special training.

The points I have tried to make in this speech are the real solidarity of the pure and the applied sciences, that the history of pure science in winning a place in the general educational system has been repeating itself in the case of applied science and that more and more the scientist is going to be called on to render social services to the nation, and that the duty lies on us who are engaged in educating the next generation to plan for a broadening of the cultural base on which we build.

AUGUSTUS TROWBRIDGE

PRINCETON UNIVERSITY,
NOVEMBER 15, 1928

THE APPORTIONMENT SITUATION IN CONGRESS

THE problem of reapportionment in Congress has two interesting aspects, one political and one scientific.

(1) On the political side, an analysis of the vote on the latest reapportionment bill (H. R. 11725, May 18, 1928) shows that the defeat of the bill (186 to 164) was due mainly to the opposition of those states which expected to lose representatives if the bill were passed. There were seventeen states which expected to lose one or more representatives, namely: Alabama, Indiana (2), Iowa (2), Kansas, Kentucky (2), Louisiana, Maine, Massachusetts, Mississippi (2), Missouri (3), Nebraska, New York, North Dakota, Pennsylvania, Tennessee, Vermont, Virginia. Every one of these states, with the exception of Massachusetts and part of New York, voted against the bill; and the vote within each state delegation (excepting New York and Pennsylvania) was practically unanimous.

On the other hand, there were eleven states which expected to gain one or more representatives, namely: Arizona, California (6), Connecticut, Florida, Michigan (4), New Jersey (2), North Carolina, Ohio (3), Oklahoma, Texas (2), Washington. Every one of these states voted in favor of the bill, the vote within each state delegation being again nearly unanimous.

The first group of 17 states controls 215 members; the second group of 11 states controls 109 members; so that in the two groups together about three quarters of the House is accounted for. The remaining twenty states, controlling 111 members, had nothing to lose or gain by the passage of the bill, and the votes from these states were about equally divided for and against.

It is obvious from this analysis that the political difficulties attending the passage of any reapportionment bill are very great. On the one hand, according to the population estimates for 1930, the only way to avoid loss to any state would be to increase the size of the House to something like 534 members. On the other hand, any proposal to enlarge the House above its present size (435) is certain to meet determined opposition both in and out of Congress.

(2) On the scientific side, there is the question as to the choice of the best method of computation. This scientific aspect of the problem is surprisingly closely related to the political aspect, as the following brief sketch of recent history will show.

The apparently simple arithmetical problem of computing the proper assignment of a specified number of representatives to the several states in proportion to their populations was an unsolved problem for over a hundred years. Up to 1921, no scientific tests of a good apportionment were known; a variety of empirical methods were tried and later discarded, and the decennial debates in Congress were often bitter. Since 1921, however, a series of scientific papers (the latest appearing in the *Transactions* of the American Mathematical Society for January, 1928) has provided a complete mathematical analysis of the problem. It is now known that among all the possible methods, the method of equal proportions is the only one which satisfies the very obvious test of making both the ratio of population to representatives and