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CRAFTSMANSHIP AND SCIENCE[1]

WHEN, nearly a century ago, the founders of our association drew up a statement of purposes and rules, they gave prominence to the words "to obtain more general attention for the objects of science." Since that time we have tried continuously to fulfil our self-imposed task, not, I hope, unwisely nor untactfully, nor without success. For this purpose we have on many occasions and in many ways endeavored to describe the progress of our researches, and to present the consequences of discoveries as they appeared to the discoverers. With your permission, I would like this evening to add something to the story. I would claim as my justification for doing so the fact that in the last few years scientific inquiry has advanced at a rate which to all is amazing, and to some is even alarming. On the one hand, the application of science to industry has become increasingly important and obvious, as was so clearly shown by our honored president of two years ago. Especially at the present time when our country is struggling to free itself from distress due partly to the war and partly to violent changes in economic conditions, is it of interest and importance to consider what science is doing and can do to accelerate recovery. On the other hand, in the less material realms the applications of recent research have aroused wide interest, as may be exemplified by the influence on philosophic thought of the new discoveries in physical science, or by the effect of last year's remarkable address from this chair.

I can not deal in the time allotted to me with all the issues that are suggested by these considerations. I propose to limit myself in a manner which my choice of title will suggest, and in speaking of "craftsmanship and science" to pay attention more particularly to the relations between science and craftsmanship of our own country. I shall not, however, be able to confine myself strictly within these limits because the entrance of science into our most material businesses can not be considered without reference to the part that science plays in the whole range of our thoughts and actions.

The term craftsmanship requires definition. I am supposing it to mean the skill which is exercised in the production of whatever is wanted for human wel-

[1] Address of the president of the British Association for the Advancement of Science, Glasgow, Scotland, September, 1928.

fare. Imagine an island so cut off from the rest of the world that its inhabitants must depend on themselves for the satisfaction of all their desires, for their food, even if they have no more to do than pick fruit from a tree, for their clothing, for their housing, and other material things. They must also find their own means of satisfying less material cravings: for if they have intelligence they will look for means of studying themselves, their neighbors and the world round about them. Their eyes and ears will ask to be used for the satisfaction of a sense of beauty in form and color and sound, and their minds will try to reach out beyond what can be seen and heard. It is impossible to proceed to the satisfaction of these desires without the handling of materials, and craftsmanship begins with the skill exercised in the handling.

What the islanders succeed in achieving by their craftsmanship may justly be described as their wages, they being their own employers. If their wages are to be raised they must somehow increase one or more of the factors on which their success depends. They must be more diligent in the discovery of materials for which a use can be found; they must become better acquainted with the properties of those materials; they must develop their constructive skill. If they are too primitive to have developed the use of mechanical power, they must do everything with their own hands, guided by their own intelligence and their own feeling for what is beautiful and fitting. At every step enter the qualities that go to make craftsmanship, as I would interpret the term. There is knowledge of materials, there is imagination, there is technical skill; perseverance is wanted, love of the work itself, sympathy with the use that is to be made of it, and with the user. Clearly, on the craftsmanship of the islanders will depend whether they have enough food to go round, enough clothes to wear, whether they have leisure for anything beyond the labor that satisfies their barest necessities.

And, of course, this isolated group of people will have some characteristic estimation of what kind of wages they want. Their energies may conceivably be devoted only to the production of things that satisfy bodily desires, or they may be bent also on nobler things. I need not consider that point as I am not trying to picture Utopia. All that this image is meant to convey is the idea of craftsmanship and its fundamental importance. Nor is the account yet complete; far from it. It is not only that the products of craftsmanship are a necessity if the islanders are to live at all; craftsmanship has a value in itself. There is in men, more in some, less in others, the natural desire to use what faculties they possess. It is a fact that love of good work and delight in successful accomplishment are powerful motives, and when satisfied are sources of real happiness. Of all the motives that sway the world these are among the purest and best.

The power to produce in plenty what is wanted is, of course, only one of the great problems that a community has to consider. There is also the endlessly difficult question of distribution, of the manner in which each working individual is to receive his share of the wages. The two problems can not be separated entirely; the means directed to the solution of one contribute to the solution of the other. But I must not attempt too much; science is in the first instance concerned with the production problem: the distribution problem follows.

Let us extend our image a little; let our island be discovered and put into communication with the outside world. An exchange of craft work sets in; the islanders discover new wants that must be satisfied and they pay for the necessary imports by exporting what they make themselves. But the exports must be made to satisfy the tastes of the outside peoples or there will be no trade. So the islanders now find that they must no longer consider their own tastes entirely; they must accommodate themselves to a more general conception which is only in part their own. It may happen that under the new conditions they become less and less self-contained. Some things which are necessary to life, such as food or clothing, may become imports, being no longer produced, at any rate in sufficient quantity, within the island itself. And now the people are very firmly tied to the rest of the world; they must give that they may receive, and they must please in order that others may be willing to take. We may say that their craftsmanship is now judged more critically: and more than ever it becomes fundamental to well-being, even to existence. The conclusion I would draw from this very simple little analogy is that a people lives on what it makes or earns and that its success depends on its craftsmanship. A people can not expect to be provided for; it has no rights.

I would ask you presently to consider the difference between the craftsmanship of an early civilization and that of our own more complicated times. But before doing so, let me say yet one or two words about the older forms.

We have a profound feeling for any example of an old craft, and for very good reasons. Among them I do not include the sentimental regret that, in some cases, a past time skill seems to have disappeared. We may be sorry, but after all it is but a receipt that has been lost and may be found again any day, if proper search is made for it. Modern knowledge and methods of analysis are at least good for that much. Nor is the collector's pride of rarity the worthiest feeling that the old specimen inspires.

Our affection for it and the reverential care with which we handle it are due to the fact that it represents to us the labor of a people, labor into which knowledge, imagination, love of beauty, technical skill have all entered. The most of what was once used in every-day life has long disappeared; even such more durable things as houses and ships, roads and cultivations may have ceased to be. The few objects that survive must be taken as examples of what has been lost. And on the showing of the student a spirit will emerge from an old vessel as great as that which issued when the fisherman of the Arabian Nights unsealed the pot that had long been lying at the bottom of the river. It is the spirit of the bygone people that takes shape before us.

The Greek gave exquisite form to his vase and decorated its surface with equal art. He copied from the growing things of nature the adjustment of lines and surfaces which give the sense of fitness for a purpose. The outlines of his vases are so perfectly adjusted that their representation in a drawing will not bear alteration by the width of a line. That the Greek should with so much skill take lessons from what his perception made clear to him, and should with so much care choose his materials and mold them to his purpose is what we should expect from a nation that shows also in its literature a passion for justice and harmony. The fine accuracy of his line is in agreement with his delicate sense of differences in thought and words.

The Roman developed the principle of the arch, and enough remains of what he built to show the daring and the power of his work. The great arches that spanned his public buildings seem to stand for the Roman rule and law under which the whole world might find shelter and be at peace.

The sword of the Indian workman was gradually brought to its temper by an infinite series of local applications of heat alternating with the few blows that could be skilfully given while for a moment it was in the workable state. The poverty of the craftsman's appliances, the meagerness of his little fire and the scantiness of the tools with which he made his way bit by bit to his final achievement are in consonance with his life of small details ruled by overmastering ideas.

I need not illustrate further. It is indeed well known to you all that the craftsmanship of a people is an expression of the best of its very self. It is to the underlying reason that I would draw your attention now. The mind of a nation is so expressed because its craftsmanship, interpreted in its widest sense, represents its efforts to live. Under this strong compulsion the nation produces results which range from pots to poetry, and all its products are stamped alike. That which we do ourselves is as representative as a Greek vase or a Roman aqueduct or a suit of armor from Milan. The craftsmanship of a nation is its very life. Even if we consider it only in relation to the production of material things, the state of a nation's craftsmanship is an index of its health.

As a people departs from its primitive condition so also does its craftsmanship. I would ask you to consider the nature of the change. The elements of craftsmanship in its original form center round the individual. In his brain is the knowledge and imagination, in his hands is the skill, and round about him lie the materials and the tools of his craft. But as the years go by it becomes impossible that all the knowledge and all the technical skill should be found in one person, and all the tools be owned by him. The craftsman becomes an association of men, a great manufacturing firm, even, we might say, a nation, if all the members of the nation contribute through government intervention and control to the maintenance of some industry. Many hands, working in an alliance which is often unconscious, are employed in bringing a product to its finished form. It is a long step from the simple workshop of the old single-handed craftsman to the vast complex factory of modern industry.

If now we ask ourselves what has brought us to this new kind of modern craftsmanship, this dependence on machinery with its wealth of production, its clattering, bustling activity and its compelling influence on the lives of all of us, we find that one simple cause has been continuously operative. It is nothing more nor less than the urgent wish of the individual to better his own condition: and in his disinterested moods, the condition of his neighbors. The change could never have been prevented.

When Hargreaves thought that by a mechanical arrangement he could manipulate several spinning wheels at one time, and succeeded, so that he had more wages to spend on his wife and children, he was obeying a universal and natural impulse. Hargreaves's neighbors being left behind in the competition for wages, pulled his house about his ears. But in the end, they, too, found themselves to be turning many spinning wheels where formerly they had only handled one. Then they, too, had more money to spend. What other turn could things have taken under the circumstances? What happened in this isolated incident is repeated again and again in every craft, and in sequence change and change marks the road that stretches far from its beginnings.

Quite apart from all considerations as to whether the new is better or worse than the old, more beautiful or less beautiful, whether it calls out the best in man as well as the older ways, or whether it fails to do so, apart from all comparisons of this kind stands the fact that the change is due to natural impulses which will not be gainsaid. The results have to be accepted. We can not put the clock back. We can not, let us say, wipe away the great steel works of the world and replace them by thousands of individuals each with his single anvil and single hammer. We can not replace the great ships of Glasgow by a multiude of little sailing boats. The plain truth is that modern craftsmanship with all its noise and ugliness is giving food and clothing, warmth and interest to millions who otherwise must die. It is ungrateful to find fault except with sympathy. Let us try in all possible ways to mend its offenses and soften its hardships, but in all honesty let us recognize that we live on modern craftsmanship in its modern form. We are each and every one of us responsible for the present conditions as long as we insist on spending money to the best advantage.

At this point it is convenient to refer to a matter which would be of little importance if it did not seem sometimes to put modern craftsmanship in a wrong light. We are continually discovering instances of the marvelous skill of the craftsman of thousands of years ago. There is here, however, no disheartening implication, as has sometimes been asserted, that men can no longer do what was once in their power. To those who look into what goes on in a factory or a mine, in the field or on the sea, there are innumerable instances of beautiful craft work, beautiful because of their fitness for their purpose, their balance of design, their ingenuity, their history, their growth under human perseverance and thought. Every one of us can bring to mind instances of technical skill demanding imagination and intelligence as well as manipulative power which could be set alongside any instance in history. Let me name only one: Could anything surpass the drawing of fibers of quartz, finer by far than a human hair, by means of the bow and arrow? It was a feat to imagine that it could be done, to anticipate that when done it would fill so perfectly an urgent need in the construction of many important instruments and, finally, to do it.

Now we come to the point at which I would ask you to consider the relation of science to the craftsmanship which I have been trying to define. I would draw your attention to the manner in which, under the urgent drive of self-preservation, the craftsman has called scientific knowledge to his aid. Sometimes the moment has been dramatic on account of the great need of the occasion and the prompt effectiveness of the reply. When, for example, coal mining was at a low ebb because the mines were becoming waterlogged and no available power was strong enough to clear them, Savery and Newcomen made use of the new discoveries respecting the pressures of gases and vapors which Torricelli and Pascal, Papin and Hooke, had just been examining and trying to explain. The steam engine thus came into being and saved the situation. And when, at a somewhat later date, your own citizen, James Watt, by further application of the same physical laws, added fresh powers to the engine, the modern steam engine came into view, with all its applications to railways and steamships and many other marvels of to-day. In 1831 Faraday, in the course of certain systematic searchings, found out the way in which one electric current could bring another into being, the so-called electromagnetic induction. With that single day's work began the whole development of electrical engineering in its innumerable forms. I need not increase the number of my illustrations.

More often it happens that scientific knowledge enters with less instantaneous and startling effect into the history of a craft. It is only when you come to consider the various details of some modern product of craftsmanship that you suddenly realize how closely every detail is connected with the advance of science and, indeed, to be more particular, with the scientific laboratory. Let us think for a moment of one of those magnificent ships for which the Clyde is famous. Let us survey its various parts in our minds. Its hull of steel recalls the great forges of Britain, and the wealth of research that has been spent in works and metallurgical laboratories on the nature and qualities of steels of all kinds, research which is still in progress. Within are the engines, turbines perhaps, or reciprocating, or it may be internal combustion engines, Diesel or others. What a range of inquiry and trial and development lies in every detail, depending always on principles of physical and chemical science, tested at every stage by instruments which are a craft in themselves! You may think of the screw and of its design. You picture the curious and most efficient thrust-block by which the force of the screw is brought to bear upon the ship, and remember that Michell lately designed it on the basis of the physical laws of liquids. You look aloft and see the wireless and are reminded that this sprang directly from the physical laboratory. Your sounding apparatus is based on your own Kelvin's designs; it may be that you have fitted your ship with the wonderful and still more recent apparatus for sounding by echo, which enables her to find the depth of water, shallow or deep, even when she is traveling at high speed. The war forced this adaptation of the laws of acousties. She is sure to carry some form of refrigerating apparatus, and now we are reminded of all the investigations into the production of cold by students of science like the Frenchmen Cailletet and Pictet, by Onnes in Holland and by Dewar, whom, as befits the occasion, I will call a Scotsman rather than an Englishman. And so on, from one great feature of the ship to another, and presently from detail to detail: and you find that the whole structure is linked by innumerable ties to the research work of the laboratories. Craftsmanship in its urgent need has called upon scientific knowledge for aid, and the mighty growth is due to the response. Indeed, it is not only craftsmanship that has grown, but science itself.

If you hinder the growth of science in any way you hinder the growth of craftsmanship. Now it is an important fact that science advances over a wide front, and the various branches of it move on together, not absolutely keeping step with each other, but preserving a general line. It has been suggested that science might refrain from development in some directions or, even as our good friend the Bishop of Ripon said at Leeds last year, we might proclaim a ten years' holiday. But you can not prevent interested men from making inquiry. You can not prevent the growth of knowledge, you can not even make a selection of those points of advance which will lead to certain select classes of results. No one knows what is over the hill. The vanguard moves on without any thought of what is before it. That is why, if the march of science is to be conducted in an effective and orderly way, were it only for the purposes of industry, there must always be a certain number of laboratories or parts of laboratories where scientific research has no immediate thought of possible applications.

If I read modern industrial conditions rightly the closeness of the connection between craftsmanship and science may be illustrated in yet another way. It is, I think, a fact, and a remarkable fact, that the most active of our modern industries are those which are founded on recent scientific research. The most notable is, of course, that of electrical engineering. The year that sees the celebration of our association's centenary will witness also the ceremonies that commemorate the basic experiment of Faraday. It is difficult to sketch in a few words the great edifices that have been built upon the discovery of electromagnetic induction. We might look upon it financially and picture, as some of my hearers can do, the amount of capital involved in electrical undertakings throughout the world, electric lighting, electric transmission of power, cables and now wireless, not to mention all the minor uses to which electricity is put. The transference of matter, of intelligence, of thought, of sound, even of vision, is largely dependent on electromagnetic action. If we are not familiar with financial quantities, let us just think for a moment of the change in our lives if every electric current ceased to run; and let us realize that the whole mechanism of modern intercourse would fail and that populations born to use it would be brought to dire distress.

Though the electrical engineering industry with all its branches may be said to have its source in a single laboratory experiment, yet it has grown by the continuous adaptation of fresh streams of knowledge. The huge American corporations maintain research laboratories costing millions of pounds annually, and find that the financial return justifies their policy. The General Electric Company found that a costly research into the structure of the electric lamp repaid itself over and over again. The very important technical discoveries of Langmuir and Coolidge were consequent upon an attempt to find out what happened on the surfaces of the glass bulb and of the glowing filament. The point is that the electrical industry was not merely launched by a single discovery; it is continually guided, strengthened and extended by unremitting research.

Consider the very active motor industry. The most important of all the problems connected with the internal combustion engine is that of the nature of the explosion, the effects of varying the mixture, the movement of the gas in the cylinder before the ignition, the actual occurrences at the moment of ignition, the movement of the subsequent explosion wave. The problems are exceedingly intricate. They have been and are the subject of intense research in various laboratories in this country. The research is new and the industry is new. The construction of the engine depends on the use of alloys possessing the most remarkable properties, all of which were practically unknown until recent researches of the metallurgists brought them to light. The motor car is connected, too, with the laboratories in which chemistry and physics are applied to the study of rubber. Here again is a whole story in itself, which would tell of the work done on the intricate consequences of various kinds of mixings and of treatment, of the vulcanizing and of the use of "fillers." Not many know the story; they are only aware that motor car tires last longer than was once the case.

The aeroplane, like the motor car, has become possible because of the advent of the internal combustion engine: but it has a unique feature—its element of romance, its motion through the air. The laws of aerodynamics are becoming better known, and with every advance in their knowledge the efficiency of the aeroplane increases. Their intricacy is gradually resolved, but the process demands, in the first place, mathematical skill, and in the second the fascinating research that is carried on in the wind channels of our laboratories. On this splendid work the progress of the aeroplane depends. I saw not long ago in a London shop-window a colored print of a flying machine. From across the street it might easily have been taken for a drawing of a modern aeroplane; a closer view showed still the same general spread of wings, the same whirling screws, the same discharge from the exhaust, a boat not at all untrue to modern design, and wheels to bear it when on land. Moreover the proportions were quite familiar. Yet the date was 1843. For all its resemblance to the modern aeroplane, how far it was from flying not only in time but in capacity! The difference between old and new in the form and materials of the wings may not be obvious to the casual observer, but in reality a wealth of trial and calculation lies between the crude projections of the old invention and the modern machine that flies. The turn of a line in the sectional outline of the wing may make the difference between success and failure, though it is only one of innumerable and equally essential details. The scientific worker grasps the meaning of that turn, and the airman tries it out, and that is the combination which brings success at last. The point is that the construction of the flying machine is a new industry based directly on knowledge recently acquired in the laboratories and continually growing under laboratory experiment. Everything depends on this careful, well-informed concentration on essential details.

If we enter the chemical province we find that there are thriving industries based on recent scientific discovery, instances at least as remarkable as those possessing a more physical basis. The chemical industries are so many and various that even a brief summary is beyond me: yet the whole of them are of comparatively recent origin. Quantitative chemistry is little more than a century old. And the more modern and more vigorous of the chemical industries depend on very recent chemical research, as, for example, those which deal with dyes, explosives, fertilizers, rubber, artificial silk and many other things. It is the same story; the craft is based on science, and in this case very obviously so. Chemical industries are based on scientific discovery, and lean on it the whole time.

It is natural to compare the condition of the newer industries with the older industries known as basic because they have long constituted by far the major portion of the country's industrial effort and are still preeminent: coal and steel, cotton and wool. In some of these industries there is serious depression. What has the fact to do with science and scientific research?

It is obvious that we can not say of any industry or craft that its condition depends only on scientific knowledge and imagination. The difficulties of the coal trade are due in large part to the powerful cause of competition. We had a good start in the knowledge of the existence of our coal deposits and in the practice of working them, in the means of distributing coal and in methods of making use of it. We reaped our harvest. But as time went on other nations gathered way in pursuit of us; they also found coal deposits, they learnt how to work them and could even improve on our practice because they could profit by our mistakes to a greater extent than we ourselves. They had not so much old machinery to scrap. Means of transit were developed in these countries; in fact we helped to develop them, as also the industries that used the coal. Such conditions must inevitably have tended to diminish our lead. The war acted suddenly and violently in the same direction. It is reasonable, though deplorable, that the industry should find itself in difficulties. The situation is not wholly irremediable, though the older conditions can never completely return. But at least a partial retrievement is possible, and we know that various research organizations, some instituted by the state and some due to private enterprise, are grappling with the question involved. It is deeply interesting to see in what way the necessary efforts are being made, and indeed must be made.

Now, whatever is done, and in whatever way it is done, the results of such endeavor, whether related to the coal or to any other industry, depend on those relations between craftsmanship and science which I have been trying to define. I would now consider these relations from one or two separate points of view. In the first instance let me say a word concerning the general connection between science and that condition in industry which is known as mass production.

It must always be the aim of an industrial organization to devise and set going one of those systems of manufacture on a large scale with which we have become familiar in recent years. With the aid of suitably designed machinery and methods, great numbers or quantities of some article in general demand can be produced at a comparatively small running cost. Generally, however, the initial cost is heavy, for the designing of the machinery and the planting of the methods call for great experience and skill, and they demand much time spent in the acquirement of the necessary knowledge and its utilization in design. Once the process is under way it may be possible, and it seems to happen on a sufficiently attractive number of occasions, that a smooth and peaceful running of the machinery brings in the wished-for returns. But every such phase of production comes to a natural end. An improved process is devised, and the new displaces the old. Or it may be a factory is set up in another country where laborers can be hired more cheaply; they may be intrinsically inferior, but that will not matter if they can be drilled into the mechanical process: and, as long as the machine runs true, the standard will not fall below a certain value. The event is in accord with expectation because men will always try to improve their productivity by the use of new knowledge or more favorable conditions, so that those who fail to recognize the principle will be left behind by those who do not. The stereotyping of some process can only be fruitful for its allotted time. Mass production is in its way splendid, ministering to the necessities and conveniences of many who must otherwise have gone without. But, if it is brought to such a pitch that its processes call for little intelligence in their working, then cheap people of little intelligence will be found, in the end, to be in charge.

The relation of science to mass production is therefore both that of builder and that of destroyer. Mass productions are temporary lulls in the movement of imagination and knowledge. Much skill and thought and care may be required to arrange for one of those quiet and profitable times; the machine is set going and for a while goes by itself. But new applications of scientific knowledge, new ideas, new processes, new machines must always be in preparation. In the parks the gardeners are always nursing fresh plants to take the place of the old, and preparing them for their useful time of flowering. And so we see the meanings of the various research organizations which have been set up in the basic industries, such as the Fuel Research Board, the Cotton, the Woolen and the Silk Research Associations, the research laboratories of the steel masters at Sheffield. Much of our hope for the future is built upon their work.

If craftsmanship, to fulfil its task of providing for the people, must be continually improving its processes, then the nation that is to be successful must possess the means and the will to improve, and here we come, I think, to a notable point. May it not be said that in this country the means exist even to a remarkable degree? Our craftsmen as a whole, including all grades, are possessed of qualities, intelligence, skill, accuracy, and so on, which make improvement possible. How could our enterprises in the past have been so often successful if this had not been so? How can we be succeeding so well in respect to the new industries of the present if the capacity is not there?

Should it not, therefore, be our policy to take advantage of our country's qualities by continually seeking for fresh industries or fresh adaptations of the old? We should not surely cling unduly to older activities when they have reached the stage in which many others have learned to do them with equal efficiency, and when we can go on to something new and, it may be, more difficult. We can, of course, bolster up old industries by political methods, and I have no wish to decry such methods as always incorrect. But clearly the best protection of all is the knowledge and skill which can enable us to produce what others must ask us for because they can not so well make it themselves.

These considerations lead naturally to a second aspect of the relations between craftsmanship and science. The improvement of craftsmanship depends in large part on the absorption and adaptation of scientific discovery. How is the process to be encouraged?

We here come to a point which must be emphasized with all possible vigor, because its importance is not always realized. Scientific knowledge and experience, if it is to be of full service, must be in direct practical contact with the problem that is to be solved. This must be clear to every one of us from actual experience. If you have expert knowledge on any subject and your advice is asked, your first instinct is, as you all know, to ask to be allowed to see for yourself. It is only when all the circumstances are clear to you in their relation to the difficulty that the solution is likely to suggest itself. And it may take much watching and patient observation before you are successful. It is the combination of actual experience with scientific knowledge that is essential. As the principle is so fundamental, I may be allowed to illustrate it by an actual experience.

It was in the early years of the war that a body of young scientific students from our universities was assembled for the purpose of testing on the battlefield the value of such methods of locating enemy guns as were already known. In their mutual discussions and considerations it became clear to them that the great desideratum was a method of measuring very exactly the time of arrival of the air pulse, due to the discharge of the gun, at various stations in their own lines. If the relative positions of the stations were accurately known it would then become a matter of calculation to find the gun position. But the pulse was very feeble; how could it be registered? Various methods were considered, and among them was one which no doubt seemed far-fetched and unlikely to be successful. A fine wire is made to carry an electric current by which it is heated. If it is chilled for example, by a puff of cold air, the resistance to the passage of the current increases, and this is an effect which can be measured if it is large enough. If, then, the hot wire could be made to register the arrival of the air pulse from the gun, a solution of the problem was in hand. No doubt this method occurred to several members of the company; it was certainly turned over in the mind of one of them who had had considerable experience of these fine heated wires. They had been in use about thirty years, having been employed for the measurement of temperature in many circumstances where their peculiar characteristics gave them the supremacy over thermometers of the ordinary form. But, and this was the important point, was it to be expected that the effect, though it must be there, would be big enough to see? Could the faint impulse from a gun miles away produce an obvious chill in a hot wire? On first thoughts it did not seem likely, and the suggestion lay in abeyance.

But it happened that one summer morning an enemy aeroplane came over at daybreak on a patrolling expedition. The officer of whom I have spoken lay awake in his bunk listening to the discharges of the anti-aircraft guns and the more distant explosions of their shells. Every now and then a faint whistling sound seemed to be connected with the louder sounds. The wall of the hut was of felt; it was in poor condition and there were tiny rents close to his head as he lay. The gun pulses made a feeble sound as they came through. This set the officer thinking; if the pulse was strong enough to make a sound, it might be strong enough to chill a hot wire perceptibly. So the method was proposed to the company as worth trying. It was tried, and proved to be a complete success. The sound ranging of the British armies was based upon it, with results which have already been described and are fairly well known.

It is clear that the all-important suggestion could only have been made by a man who had had scientific training and experience. That is one point of the first significance. The second is that it could only have been made by such a man actually on the spot. He could not have realized the details of the problem if he had been anywhere else.

It is worth while to consider this last point a little more closely. What precisely was the difficulty which could only be resolved by a combination of knowledge and of being on the spot? It was really the difficulty of making a true estimation of quantities. It was a question of magnitudes and measurements. Any one possessed of scientific knowledge could have said, if asked, that a gun must make an air pulse, and that an air pulse would chill a hot wire to an extent which might or might not be measurable. But there is all the difference in the world between such vague general knowledge on the one hand, and, on the other, the realization that such a method is likely to work and give the desired result. It is the difference which so often escapes attention, but every one of experience knows that it is to be reckoned among the essentials. It is so easy to talk generalities or to think of them, and so difficult to get down to the details which make the effort a success. It may be the last little adjustment of magnitudes that turns the scale, and the last step the one that counts.

Are we, then, in this country, putting our scientific knowledge into the position where it is really effective? I would draw your attention to a most interesting and important movement which is attaining a notable magnitude.

A new class of worker is growing up among us, consisting of the men engaged in research associations and industrial research laboratories throughout the country. We must place a high value on their services, for they are actually and personally bringing back with them into craftsmanship the scientific knowledge which is one of its essentials. They bring the interest and the outlook of scientific inquiry into touch with both employer and employed, and I can not but think that they may be to some extent the flux that will make them run together. For they can speak with the employer as men also trained in university and college, exchanging thought with ease and accuracy. And, at the same time, they are fellow workers with those in the shops and can bring back there some of the interest and enthusiasm which springs from the understanding of purposes and methods. It is to be remembered always that personal contact has, on the whole, thanks to the better qualities in human nature, a marvelous effect in smoothing out differences. I do not think it is unduly optimistic to welcome the growth of this new type of industrial worker because it can, being in personal intercourse with both capital and labor, supply to each a new outlook on their whole enterprise, especially as that outlook is naturally illuminating and suggestive. For, after all, this is but going back to first conditions. The primitive craftsman has been replaced by separate persons or groups of persons 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 good 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?

The present number of industrial research workers is relatively small; it seems likely to increase, however, in proportion to the extent to which the province of science is better understood. The better understanding I think of as manifesting in the first place in industry itself. I am sure that here it is happily on the increase. There is also a broader view to be taken. There is a public estimation of the value of any calling which affects the numbers and the quality of those who respond.

I doubt if there is in the first place sufficient appreciation of the interests and rewards in the life of a student of industrial research. The pioneers have suffered unnecessary restrictions and discouragements, but their followers will be in better case. Surely it does not need much imagination to realize the splendid side of such work? The succession of fresh difficulties to be overcome, and of new and interesting views into the nature of things and ways of the world: the unforeseen value of results, sometimes an immediate prize, sometimes the clearing of an obstacle in a manufacturing process, never less than the discovery of facts which may some day be of use: the personal association with a living enterprise and with the human spirit behind it. And when it is realized that this kind of work is wanted badly, that it is really serviceable to the community, that there is opportunity for devotion, that it is in touch at once with human needs and with the furthest stretches of thought and imagination, it surely takes on to us the final touch of nobility.

We must remember also that the road of the student of science is still none too clear. The very methods of teaching science are a constant subject of discussion. I will say no more now than this: that the best methods must take time to elaborate, and can not be expected to have arrived at their final form. The difficulty is increased by the fact that science itself grows rapidly, and the extent of its application is only now revealing itself. That the knowledge of the immensity of nature and the study of the natural laws have an educative value is well recognized. That science can be used as an educational drill is also known and made use of. But there still remains the human side: the continuous effect of the growth of knowledge upon thought and enterprise, the realization of the immense part that science is playing in modern life and is likely to go on playing. Education by scientific instruction is still apt to lack the comprehension of the human side, without which the classroom is a dull place.

There are even some who think that science is inhuman. They speak or write as if students of modern science would destroy reverence and faith. I do not know how that can be said of the student who stands daily in the presence of what seems to him to be infinite. Let us look at this point a little more closely.

The growth of knowledge never makes an old craft seem poor and negligible. On the contrary it often happens that under new light it grows in our interest and respect. Science lives on experiment: and if a tool or a process has gradually taken shape from the experience of centuries, science seizes on the results as those of an experiment of special value. She is not so foolish as to throw away that in which the slowly gathered wisdom of ages is stored. In this she is a conservative of conservatives.

What is true of a tool or process is true also of those formulae in which growing science has tried to describe her discoveries. A new discovery seems at first sight to make an old hypothesis or definition become obsolete. The words can not be stretched to cover a wider meaning. By no means, however, is that which is old to be thrown away; it has been the best possible attempt to express what was understood at the time when it was formed. The new is to be preferred for its better ability to contain the results of a wider experience. But in its time it will also be put aside. It is by a series of successive steps that we approach the truth: each step reached with the help of that which preceded it.

Nothing in the progress of science, and more particularly of modern science, is so impressive as the growing appreciation of the immensity of what awaits discovery, and the contrasted feebleness of our ability to put into words even so much as we already dimly apprehend. Let me take an example from the world of the physical sciences. There is a problem of which the minds of physicists have been full in recent years. The nineteenth-century theory of radiation asks us to look on light as a series of waves in an all-pervading ether. The theory has been marvelously successful, and the great advances of nineteenth-century physics were largely based upon it. It can satisfy the fundamental test of all theories, for it can predict the occurrence of effects which can be tested by experiment and found to be correct. There is no question of its truth in the ordinary sense.

In the last twenty or thirty years a vast new field of optical research has been opened up, and among the curious things we have found is the fact that light has the properties of a stream of very minute particles. Only on that hypothesis can many experimental facts be explained. A wave theory is of no use in the newer field. How are the two views to be reconciled? How can anything be at once a wave and a particle? I do not believe that I am unjust to any existing thinker if I say that no one yet has bridged the gap. Some of you who were present at the Liverpool meeting may remember that Bohr—one of the leading physicists of the world—doubted if the human mind was yet sufficiently developed to the stage in which it would be able to grasp the whole explanation. It may be a step forward to say, as we have been saying vaguely for some years, that both theories are true, that there are corpuscles and there are waves and that the former are actually responsible for the transference of energy in light and heat, and for making us see: while the latter guide the former on their way. This is going back to Newton, who expressed ideas of this kind in his "Opticks," though he was careful to add that they were no more than a suggestion.

We are here face to face with a strange problem. We know that there must be a reconcilement of our contradictory experiments; it is surely our conceptions of the truth which are at fault, though each conception seems valid and proved. There must be a truth which is greater than any of our descriptions of it. Here is an actual case where the human mind is brought face to face with its own defects. What can we do? What do we do? As physicists we use either hypothesis according to the range of experiences that we wish to consider. To repeat a phrase which I employed a few years ago in addressing a university audience familiar with lecture time-tables, on Mondays, Wednesdays and Fridays we adopt the one hypothesis, on Tuesdays, Thursdays and Saturdays the other. We know that we can not be seeing clearly and fully in either case, but are perfectly content to work and wait for the complete understanding.

And when we look back over the two centuries or so during which scientific men have tried systematically to solve the riddle of light, or even go further back to the surmisings of philosophers of still older time, we see that every conscientious attempt has made some approach to the goal. The theories of one time are supplanted by those of a succeeding time, and those again yield to something more like the first. But it is no idle series of changes, no vagaries of whimsical fashion; it is growth. The older never becomes invalid, and the new respects the old because that is the case.

Surely it is the same in regard to less material affairs. The scientific worker is the last man in the world to throw away hastily an old faith or convention or to think that discovery must bring contempt on tradition.

There is a curious parallelism here to a relation between science and industry of which I have already spoken. Just as any particular case of mass production can be regarded as a temporary condition which the growth of knowledge brings about, and in the end supersedes, so also it may be said of any law or rule or convention or definition that knowledge is both the parent and eventually the destroyer. Time devours his own children. Even if a statement retains its outward form, its contents change with the meanings attached to its terms: and change moreover in different directions when used by different people, so that constant redefinition is necessary. How much more is this the case when the contents themselves have to be added to. The distinction between truth itself and attempts to embody it in words is so constantly forced upon the student of science as to give his statements on all matters a characteristic form and expression. And this is, I think, one of the reasons why men are often needlessly alarmed by the new announcements of science and think they are subversive of that which has been proved by time.

To this consideration I may add yet one more, which may be illustrated by the same analogy. Scientific research in the laboratory is based on simple relations between cause and effect in the natural world. These have at times been adopted, many of us would say wrongly, as the main principle of a mechanistic theory of the universe. That relation holds in our experimental work: and as long as it does so we avail ourselves of it, necessarily and with right. But just as in the case of research into the properties of radiation we use a corpuscular theory or a wave theory according to the needs of the moment, the two theories being actually incompatible to our minds in their present development, so the use of a mechanistic theory in the laboratory does not imply that it represents all that the human mind can use or grasp on other occasions, in present or in future times.

The proper employment of scientific research is so necessary to our welfare that we can not afford to allow misconceptions to hinder it: and the worst of all are those which would suppose it to contradict the highest aims. Science, as a young friend said to me not long ago, is not setting forth to destroy the soul of the nation, but to keep body and soul together.

And some perhaps might say that in considering science in relation to craftsmanship I am pressing the less noble view that I am not considering knowledge as its own end. It is said that uselessness in science is a virtue. The accusation is a little obscure because it may justly be said that knowledge is never useless. If I have thought of science in relation to craftsmanship, it is because I have tried to set out the vast importance of what craftsmanship means and stands for. I have not forgotten that there are other aspects of the inquiry into the truths of nature.

Indeed, I could not carry out the lesser task without considering the whole meaning of science. And no clear line can be drawn between pure science and applied science: they are but two stages of development, two phases which melt into one another, and either loses virtue if dissociated from the other. The dual relation is common to many human activities and has been expressed in many ways. Long ago it was said in terms which in their comprehensiveness include all the aspirations of the searcher after knowledge: "Thou shalt love the Lord thy God with all thy heart and with all thy soul and with all thy strength" and "Thou shalt love thy neighbor as thyself." In the old story every listener, from whatever country he came, Parthians and Medes, Cretans and Arabians, heard the message in his own tongue. A great saying speaks to every man in the language which he understands. To the student of science the words mean that he is to put his whole heart into his work, believing that in some way which he can not fully comprehend it is all worth while, and that every straining to understand his surroundings is right and good: and, further, that in that way he can learn to be of use to his fellow men.

WILLIAM BRAGG

JOSEPH EDWARD KIRKWOOD

JOSEPH EDWARD KIRKWOOD was born at Cedar Rapids, Iowa, on January 24, 1872. He died suddenly, August 16, from heart failure, while engaged in research at the University Biological Station at Yellow Bay, Flathead Lake, Montana.

His mother and father were of pioneer stock, and in 1884 the family moved to Oregon to carve out a farm from the wilderness of the upper Willamette valley. He finished his preparatory and college training at Tualatin Academy and Pacific University, receiving his A.B. in 1898. A private fellowship enabled him to start his post-graduate work at Princeton University, and a graduate assistantship at Columbia University enabled him to continue his graduate study the following year. He married Ella Belinda Hoyt, of Hillsboro, Oregon, in 1901, and took her to Syracuse University, where he was an instructor from 1901 to 1904. During this period he finished the work for a master's degree at Princeton in 1902 and completed the work for the Ph.D. at Columbia in 1903. He ranked as associate professor in botany at Syracuse University from 1904 to 1907. He was made full professor and chairman of the department in 1907. During his teaching experience at Syracuse his three children, Robert Hoyt, Mary Burnette and Edward Russell, were born. During the year 1907–1908 he acted as assistant botanist with the Continental Mexican Rubber Company, Torreon, Mexico, as a member of the research staff, investigating the availability of the Guayule shrub as a source of rubber and was studying the possibility of cultivating this shrub for commercial rubber productions. The next year, 1908–9, he spent as an investigator with the Carnegie Desert Laboratory at Tucson, Arizona, carrying on research the entire year. Since 1909 he had been connected with the State University of Montana.

He came to the State University of Montana as assistant professor of botany and forestry; from 1910 to 1914 he was professor of botany and forestry, and from 1914 on was chairman of the department of botany. As chairman of the scholarship committee, chairman of the graduate study committee and as a member of the research committee he did much to build up the State University of Montana. Not only to his colleagues but to his students as well he continually urged the necessity of research as a part of the university educational program.

Despite the fact that he was faced with the task of building a department from the ground up and for many years carried the whole teaching load, he still found time for a more than creditable amount of research in his field. It is as a pioneer botanist in the northwest that he is chiefly known, and he was probably the first worker in the field of experimental forestry in the northern Rockies. His monumental work is on the trees and shrubs of the northern Rockies, the drawings for which show his infinite capacity for accuracy and artistry as well. This large work is still in manuscript, but the state university hopes to soon have it on the press; it will mean much to our understanding of the flora of this region.

From his early days at Montana he felt that the science workers of the northwest should have a scientific association of their own because they were so far removed from the science workers of the east. From its earliest days he perhaps did more than any other one man to organize the Northwest Scientific Association, serving as its chancellor in 1925 and as councilor from that time until the time of his death. His was the moving spirit behind the plans for a research laboratory and library for the science workers of the northwest, to be located as centrally as possible for the northwest, possibly at Spokane, Washington. It is to be hoped that his untimely death will not jeopardize the financing and building of such a science center.

He felt that the teaching of science in the secondary schools of the northwest was not well organized, and the members of the Inland Empire Teachers Association will testify to the fact that he did much to