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Science, Technology, and Civilization

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The interaction of science and technology is a subject that would have interested Brunel; and it is highly relevant to the advancement of your College. I find, as a physicist who is interested in the history of his subject and who has sometimes to advise on items of national policy, that my attention is frequently focused on this very interaction; it is an important factor in the development of science, and it is a unique characteristic of our civilization. There is far more to be thought and said about it than could possibly be encompassed in an hour of talking—and yet I must warn you that in this lecture I want to look also at another subject, no less interesting. This is the interaction of science and technology not with one another but with our national life as a whole.

The rise of science and technology is the most remarkable feature of our civilization. In some ways, it appears so obvious and essential that it is all the more surprising to find that in previous civilizations technology played a relatively small part, and science none. Technical processes are in fact older than human life—birds, bees and beavers all perform masterpieces of technical construction, and so no scientist could refute the thesis that the development of some degree of human technical skill preceded any conscious scientific effort. While the completely empiric development of technical processes does not constitute technology, impressive results were achieved—and still are achieved—by empiric or 'rule of thumb' methods, and these were good enough to satisfy all civilizations before ours.

Among the several ancient civilizations known to us, it is worth briefly looking at the two, the Greek and the Chinese, in which the culture of the intellect was the most highly esteemed. In Greece the earliest philosophers set out in an admirable way; they realized the value of keeping their philosophy level-headed by contact with the world of everyday experience, and they even instituted such practical tests as having a man weave the cloth for his own coat before allowing him to embark on the study of philosophy. Even Aristotle, whose followers exerted such a dead hand on creative science, urged the necessity of observation. Unfortunately, the later philosophers departed from this sobering but stimulating contact with reality, and they were led away by their intellectual triumphs into the conceit that it ought to be possible to think out the whole structure of the natural world from a few axioms. Recourse to experiment was in their view a sign of an inferior mind, a view which was no doubt reinforced by the fact that in Greece most of the manual work was done by the helots, an inferior class, so that the manual work of an experiment would be well below the dignity of a philosopher. This mistake, perpetuated in our own system of classical education, was fatal to Greek science.

The Chinese story is even more remarkable, although it seems to follow much the same pattern. It is the more remarkable because in techniques the Chinese were far above the Greeks. Chinese inventions included printing, paper, porcelain, the compass, gunpowder and the rocket—and yet science failed to develop. It is well worth asking why, but we cannot yet give the complete answer. It may well lie in the surpassing value that the Chinese placed upon the mind. The scholars were recognized as the top class of the Chinese hierarchy, followed in order by the farmers, the artisans, and the traders. The Chinese state was ably run, in a limited way, by the civil servants recruited, as are our own, by national competitive examinations from the ranks of the brightest scholars. They could ably govern, as can our own civil servants, any situation that their minds could contemplate; but they could not legislate for anything that they could not imagine. And as they stewed in their own intellectual juice, their imagination was not given the jolting stimuli that arise only from contact with the new experience gained from experiment. Perhaps the one recognized class that might have stimulated Chinese science to develop was the traders. They might have seen the utilitarian value of a scientific approach to technology; but,

from realizing the wider range of his ability by co-ordinating his physical senses with his mind. And I hope that if at some future stage of human development some other branch of learning should become of more urgency than a particular science or a particular technology, or indeed than science and technology altogether, we scientists and technologists will not seek to cramp it by our vested interests as the so-called humanists for so long did with us.

Let us now return to the proper theme of our title, in the hope that science and technology will jointly get fair play in our civilization. I should like to be sure that we do not between ourselves perpetuate that prejudice against which we have been for so long fighting the external battle. It could happen that the pure scientist, and perhaps especially the theorist, might assume the mantle of the classical scholar—he is the one whose activity most closely approaches that of the pure intellect; and any thinking man must have the very greatest respect for the achievements of the pure intellect. Let me say at once that the greatest theorists I have met were most appreciative of the earthy details of practical experimentation. But there are less good theorists who may tend to look down on contact with experiment, and less good experimenters who may rate a very moderate experiment more highly than a superb piece of technology. And undoubtedly there have been British physicists who have frowned upon the large machines in America. It is as though string and sealing wax were just admissible to assist the pure mind, but that to resort to a large machine was an admission of intellectual failure. This is a misguided viewpoint, now disappearing; the elegance of experimental method lies in achieving results with the most economical effort—and sometimes this economy may involve using large machines because small ones would be useless. I do not, of course, want to give the impression that the use of large machines or of elaborate techniques is always justified; sometimes it contributes merely to the sense of self-importance of the investigator, and it is always salutary to remember Rutherford's 'We haven't the money, so we've got to think!'

The debt of technology to pure science is so obvious that there is no need to labour it. In our own day, we have already seen radar, television, the transistor, nuclear power, and many others. And it has happened that pure scientists have deliberately initiated much technology—the Swiss watch industry was stimulated by a professor of natural philosophy, and we have already mentioned that the Royal College of Science and Technology in Glasgow owed its foundation to another professor of natural philosophy.

Apart from this deliberate stimulus to technology from pure science, there are many accidental benefits. I remember Sir Henry Tizard making the point (he did not claim it to be original) that if you had in 1895 a large bequest to make, and had decided to use it to encourage improvements in the treatment of surgical cases, you might have thought of giving the money for the development of new germicides or new anaesthetics, or for the development of new surgical instruments. It is most unlikely that you would have thought of supporting pure research on the conduction of electricity in gases. And yet it was precisely this work that was in fact to produce such an advance in surgical methods. Röntgen's discovery of x-rays in 1895 in the course of his physical researches at Würzburg was to make the task of the surgeon much easier; and x-rays were, I believe, used in the hospitals within six months of their discovery by the physicist, who had been pursuing his research without any thought of a discovery that would be such a profound benefit to medical technology.

But pure science has its own debt to technology. Earlier, I tried to show this by the historic examples of von Guericke, Black, and Rumford. Let me now quote a most distinguished theoretical physicist—Louis de Broglie, the originator of the wave concept of the electron.

> 'But there is another and less obvious point to which I should like, still simply as a scientist, to draw your attention. There is one special form of the mechanical art in which the machine becomes the servant of intellectual curiosity; this form is experimental technique—the technique which supplies the scientist with the necessary instruments for studying Nature and discovering its Laws. Every important step forward made by astronomy, physics, chemistry or biology had one essential condition—the previous existence or invention of certain apparatus; and as the sciences sought to extend their advance, so it became necessary for instrumental technique to develop and to expand in its delicate adjustments. . . . Left to itself, theoretical science would always tend to rest on its laurels; but experiment, by becoming continually more exact and delicate, has shown us more clearly each day that "there are more things in heaven and earth than are dreamt of in your philosophy." By pointing to the infinite complexity of reality, experiment has broken the circle within which speculative thought might easily risk confining itself, if left to its own devices. And since experiments depend on the perfection of experimental technique, the machine today is in a sense one of the essentials of intellectual progress.' (Address to the Lycée Pasteur, July 13, 1932.)

Examples of de Broglie's thesis continue to happen. The discovery of cosmic rays was made because of C. T. R. Wilson's care in trying to make a perfect electroscope. No matter how hard he tried, the insulation always seemed to be defective; ultimately he came to the conclusion that the air in the electroscope was very slightly ionized, and this led to the discovery of cosmic rays as the cause of the ionization. Even as de Broglie was speaking in Paris in 1932, a radio engineer in America called Jansky was trying to make as noise-free a radio receiver as possible. He noticed that the noise increased when his aerial was directed towards the Milky Way; this result, which was the start of radioastronomy, was almost ignored by the scientists until the radar experiences of World War II forced it on their attention. At the present time, our knowledge of the space around the earth owes at least as much to technology as it does to pure science. The development of rockets has depended almost entirely on technology and very little on pure science; but the explorations of space that rocket technology is making possible are already yielding results of value to the pure scientist.

It is impossible in fact to draw a clear distinction between pure science and technology; they not only interact, but they overlap. Playfair saw a happy analogy in an anecdote concerning Faraday:

> 'Faraday's first experiment, made as a newsboy while waiting outside for a paper, was to put his head

through a railing and then speculate on which side he was! Here we see the philosopher acknowledging the head as of preponderating importance, though it was incapable of being disassociated from the body. He got a practical proof of the fact, that both ought to be in good connexion; for, while he speculated, the door opened and he received a severe wrench. Faraday never afterwards disassociated his manipulative skill, great as it was, from his wise head and warm heart.' (*On Primary and Technical Education*, 1870.)

And in this connexion, it may be worth quoting some words of Lord Cherwell:

'The word "technician" is used to mean a man who has been trained to carry out established techniques which may be complex, and require a high degree of skill, or to work in a prescribed field under instruction; whereas by a "technologist" is meant a man who, as a result of broadly based studies and wide practical experience, has acquired a real understanding of scientific principles and can apply them to the development of industrial processes in diverse fields. It may sometimes be difficult to draw a sharp line of demarcation between the technician on one hand and the scientist or the technologist on the other, and nobody would like to see any barrier set up that might discourage the scientifically minded technician from becoming a scientist or technologist.' (Messel Lecture, 1954.)

All of us, scientists and technologists and technicians, should therefore see ourselves as inseparably bound together in a common effort, with the dual purpose of adding to man's understanding of the physical world, and of furthering his constructive achievements; thereby he can add to his own happiness.

Further, I would remind you that although I have in this lecture recalled the sorry record of this country in technological education, I would urge you to distinguish between the defects of the classical educationists and the merits, for there undoubtedly are some, in a study of the humanities and the arts. In our enthusiasm for science and technology, let us not forget to develop our other interests. And if at times I have appeared to take rather a national viewpoint, this is partly because it is inside the framework of our nation that most of us have to act. We must remember that despite the technological superiority of Germany, to which Playfair and Strange rightly drew so much attention, and the achievements of modern Russia, our record in the treatment of human beings is much better, thanks, perhaps, in some small part to our not being a nation of obsessed scientists and technologists.

Finally, neither science nor technology knows national frontiers; and in developing them we are sharing in a most exciting field of human endeavour—it is in the common basis of experience and of mutual respect between the scientists and technologists of one nation and of another that there lies one of the best hopes of international understanding.

I have tried to say some of the things that I think worth saying, in the hope that they will help you to understand the background against which you are working. In realizing our debt to the past, we must try also to avoid its mistakes. There are brilliant opportunities for science and technology ahead of us, and I congratulate you on deciding to share in the effort.