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The Art of Discovery

SOME years ago, at a Research Institute in London, a group of philosophically-minded members of the staff decided to hold a series of discussions on the methods and aims of science. After a while they ran short of themes and a sardonically-minded colleague suggested that they should hold a whole day meeting on the question " Is it better to work or talk about it ? " This was perhaps rather harsh, but, for the most part I have always felt that it is better to work than to talk. In particular, for me, the fascination of scientific work has been enough, and I have been content to leave the philosophical background to others. However, as time's gone on I've found that it's intriguing to stand back now and then and look at the scientist as a zoological specimen, to see what sort of a man he is and how he obtains his useful, interesting or embarrassing results. Often he's a curious sort of creature, a worthy subject for his own analytical and observational methods. In other words, the scientist is very fond of putting other things under the microscope; let's put the scientist under his own microscope.

It happens also that over the years several intriguing books have been published in England which have caused a certain amount of introspection on the part of the scientist. The latest of these is a little book by Professor Beveridge of Cambridge on *The Art of Scientific Investigation*. The use of the word " art " in this connection is perhaps surprising. Art and science are usually thought of as being fundamentally different. Professor Beveridge, however, in writing this book had in mind investigations leading to major discoveries, and he analyses the circumstances attending such discoveries and the mental characteristics of those responsible. His conclusions clearly justify the use of the word " art." The word " investigation " is perhaps less fortunate. It suggests vistas of plodding routine. I hope that I have given a rather different impression in calling this paper the " Art of Discovery."

I want to examine the idea that creative research is essentially an art ; to talk to you about the psyche of discovery rather than the technology of investigation. In taking this as my text, I am thinking mainly of those who extend the frontiers of knowledge rather than of those who consolidate and exploit the newly won territory. In doing so, however, I do not wish to imply that one is more important than the other. Both play an essential part. I should add that I am thinking mainly of the biologist, in the widest meaning of the word. The medical man, for instance, is a biologist in the sense that he deals with material which is living—at any rate to start with. In these days, also, I must take shelter behind the clause now incorporated in the Statutes of the Royal Society of London, that words importing the male sex shall include the female. In other words, women scientists are now playing an important part in the advance of knowledge.

First of all, what are the intellectual weapons with which a scientist must be armed ? The once popular conception of the research worker as an absent-minded old gentleman or else as a sort of human calculating machine has long since disappeared, but the former had perhaps more basis than the latter. Years ago, Trotter maintained that, to perceptive minds, chance and intuition are weapons far more potent than reason and logic. Few will disagree with this contention. Many discoveries could not have been deduced from existing knowledge and could not, therefore, have been arrived at by processes of reason alone. In biology, especially, we never have all the relevant facts available, and there are nearly always alternative explanations of those we have. As a result, the development of a discovery can be planned, but the original discovery cannot. It is true, of course, that to reach the ranks of the immortals a scientist must combine exceptional inspiration with the most powerful intellectual machinery, but the fact remains that many scientists become prominent mainly by virtue of other characteristics than a capacity for reasoning. The significant conclusion follows that a distinguished scientist may be as irrational as anyone else, or even more so.

Moreover, even where reason and logic are appropriate tools, few possess them. In the last resort, there is no such thing as the disembodied intellect, and but few instances of the brain packed in ice. The scientist, like everyone else, is a puppet of his psychological and physiological make-up, and is just as likely as anyone else to think with his emotions instead of his intellect. In particular, much of what masquerades as reason comes from an attempt to rationalise, that is to justify by apparently reasoned argument a view which in reality is determined by self-interest, emotional

considerations, prejudice and the like. To the scientist this almost universal habit of rationalising may well take the form of dressing up in the garb of logical deduction a discovery made by very different means. Certainly, the sequence of a research is usually erratic and quite different from the orderly presentation aimed at in publication. Reason, therefore, is a tool of limited value. What else is available ? Let's consider the use of hypothesis, and do so by way of analogy.

A very good example, as Beveridge points out, is provided by Columbus's discovery of America ; it has many of the features of a classic discovery in science. Columbus, you will recall, was obsessed with the idea that if the earth were round he could reach the East Indies by sailing west. Notice the following points—(1) the idea was by no means original, but he had obtained some additional information from a sailer blown off his course ; (2) he met great difficulties in getting someone to provide the money as well as in making the actual experiment ; (3) he did not find the expected new route, but instead found a new half of the world ; (4) despite all evidence to the contrary he clung to the belief that he had found a new route to the Orient ; (5) he got little credit or reward during his lifetime ; (6) evidence has since been brought forward to show that he was by no means the first European to reach America.

Many discoveries in science have been made in a similar way acting on a hypothesis, and it should be added that a hypothesis may be very fruitful without being correct.

We should now consider the role of chance. It is well known to laboratory workers that chance and accident have been directly responsible for many major and a host of minor discoveries. This may come about in various ways. A well conducted experiment, designed to elucidate one problem, may, in the result, throw brilliant light on another, or some fortuitous circumstance may intervene to alter the whole bearing of the experiment, or, again, the experimenter may make a simple mistake and in doing so make a discovery. Many writers have been lured into cataloguing discoveries which have been made by chance, and many well known examples might be cited. So far as my own experience is concerned, two discoveries with which I have been associated have arisen in this way. Many years ago, when I was very inexperienced, I used female mice, in doing an experiment, when I thought I was using male, and that, or course, led to most interesting results. More recently, an even simpler and more fruitful kind of error arose merely from taking the wrong bottle off the shelf. Probably the most famous of all examples of discoveries arising by chance is the discovery of the antibacterial properties of

Penicillium. The accidental contamination of Fleming's culture by spores, which led ultimately to the discovery of penicillin, would probably not have happened at the present time when sterile rooms and filtered air would be the rule for such work. This raises a somewhat paradoxical point. In the past, chance has been a fruitful source of discovery ; but, present-day planning of research is designed, so far as possible, to eliminate chance by abolishing the wayward experiment, the fortuitous circumstance, and the absent-minded mistake. It is perhaps well to remember that in perfecting the science of investigation we may starve the art of discovery. Chance, however, does not always come to our assistance, as is well shown by the history of another group of anti-bacterial compounds. Sulphanilamide was known to the chemists more than 40 years ago, but its bacteriostatic power was not discovered until shortly before the second war. It is salutory to consider that the course of history might have been altered had the biological properties of sulphanilamide been discovered by chance or otherwise before the first war.

I must be very careful not to give the wrong impression in these remarks about chance. I do not want to imply that anyone can work in a laboratory for a few weeks, make a lot of stupid mistakes and thereby make discoveries. What I am trying to say is that if one works hard enough and long enough, with sufficient single-mindedness, then, one may perhaps make some small discovery, and, if one does, then, looking back, it will probably appear that chance has played a large part in it. At best, chance does not make discoveries unaided. Odd things happen almost every day in an active laboratory, and may make little if any impression on the observer ; those that do attract attention are often discounted as irrelevant nuisances, which is exactly what most of them are. To quote from Beveridge :

> " Anyone with alertness of mind will encounter during the course of an investigation numerous interesting side issues that might be pursued. It is a physical impossibility to follow up all of these. The majority are not worth following, a few will reward investigation, and the occasional one provides the opportunity of a lifetime. How to distinguish the promising clue is the very essence of the art of research."

This is very true, and it requires that elusive something, the ability to divine the significant happening and to appreciate its potentialities, which distinguishes the great scientist. This elusive something defies analysis, as does the genius of the great painter or composer. It is compounded of imagination, intuition, insight, flair, or what you will. Appleton, in a

recent broadcast, said, " The big things in science occur when an adventure takes place in the mind of an individual. The consequences of that adventure can be followed up by an individual or by a team of workers. But, the big steps forward in science are matters of individual enterprise." My friend and one time tutor, Dr F. H. A. Marshall of Christ's College, Cambridge, influenced the development of the physiology of reproduction to an extent out of all proportion to the volume of his scientific writing. When he died a few years ago, his obituary notice included this paragraph : " Scientists are of many kinds, but inspiration flows most fruitfully from those who are able, by some gift withheld from lesser men, to divine the richness of unchartered country and sense the vital landmarks. Thus do they avoid the barred places and the morasses of unimportant detail which engulf so many. To these, discovery is an art rather than a science, a matter of instinct rather than of intellectual machinery."

This concept of the great scientist as a creative artist has important implications. How can imagination, intuition, originality and the like, be encouraged, and what factors are likely to be inhibitory ? Beveridge points out that intuition, originating in the subconscious mind, will come to the surface only when the conscious mind is relaxed and receptive, and will do so, in fact, most readily on the fringes of consciousness. There is at least one authentic record of a biologist passing on a death-bed inspiration to his favourite pupil who was able, by a few simple experiments, to demonstrate the correctness of the idea and thereby to make a substantial contribution to knowledge. Most of us, however, would prefer not to go to our death-beds to obtain inspiration, and fortunately there are other recipes. For instance, Descartes is said to have made his discoveries while lying in bed in the morning ; Brindley, the engineer, when up against a different problem, would go to bed for several days until it was solved. Other recipes for encouraging intuition include light occupation, pottering in the garden, sitting in the bath, and the like. All this boils down to the idea that a scientist must have time and opportunity for meditation, and most not be expected to spend all his life in an intellectual steeplechase.

On the other side of this picture there is the undoubted fact that scientific insight of the highest order may go hand in hand with all sorts of unlikely characteristics, including continuous mental and physical activity. As Derrick has said, " The advent of a genius is unpredictable. He cannot be organised into any scheme, for he creates his own world. All that planning can achieve in regard to genius is to provide an environment in which he can flourish, and to pray for the grace to recognise and encou-

age him." This, of course, is not as easy as it sounds. Only a very small proportion of those taking up research are geniuses ; the others do not necessarily give of their best in conditions appropriate to creative art. It is impossible, however, to segregate the various categories which, in any case, merge imperceptibly. Nor is it desirable. Ordinary people make up the backbone of any research organisation, and extraordinary people are most inspiring when there are not too many of them. How then, to create under one roof conditions calculated to encourage the blooming of rare genius and at the same time suitable for day to day research ? This question is extremely difficult to answer, but an answer must be found if the large and highly organised research institutes now established in many parts of the world are to give of their best.

It is perhaps easier to discuss factors antagonistic to creative research. In the world western we are fortunate—mainly—in being free from the worst enemy of expanding knowledge—authoritarianism, with which seekers after new knowledge have often had to fight. Nevertheless, it is in human nature to be allergic to new ideas, and discoveries are not always received with undiluted enthusiasm. This is particularly true when the discovery impinges upon some vested interest or conflicts with the views of the scientific hierarchy. Many years ago T. H. Huxley, who had a most happy knack of epigram, said, " It is the common fate of knowledge to start as heresy and end as superstition," and it is not always easy to decide at which stage of this cycle a piece of knowledge has arrived at any particular time. Discoverers in short have inherent difficulties to contend with. They themselves may raise additional ones. Discoverers are not always the most persuasive and tactful people and, moreover, an independent thinker in science may well be an independent thinker in other ways less acceptable to authority.

We can, therefore, give some of the analytical data for the great man of science. Is it then possible to arrive at the constitutional formula and perhaps to effect a partial synthesis from more plentiful material ? One may well have doubts on this point, but a knowledge of how the great men of science have worked and how discoveries have been made in the past can hardly fail to inspire those, especially those of the younger generation, now engaged in research.

Well, these are some thoughts on the scientist and his work, prompted by a fairly long experience of research. In conclusion I would say this. A man engaged in creative science is often regarded as doing a desirable and rewarding job under pleasant conditions. This is undoubtedly true, but it is only half the picture. Research is compounded of work, hope,

doubt, bafflement, and more work, and at the end of it all disappointment is more common than even minor triumph. Years of work along a particular line may end in nothing, or success may be anticipated by someone else. Chance, too, is a fickle friend and works more often against the researcher than in his favour. Yet, every day of active research work is an adventure, exasperating, fascinating, satisfying. To some, scientific research is a profession ; to others, it is a vocation ; to all of us it is a way of life which few would willingly forsake.

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