DOUBT AND CERTAINTY IN SCIENCE

A Biologist's Reflections on the Brain

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PREFACE

To the Galaxy Books Edition

MUCH OF THE MATERIAL of this book was delivered ten years ago as the Reith Lectures; but, as it deals with some fundamental problems of biology, I hope that it still has some value. Indeed, one feeling on re-reading it has been of disappointment at the relatively slight development in the meantime of our knowledge of the nervous system. Many new facts have been discovered every year, but we still have only a very incomplete understanding of how the brain works.

The nerve impulses by which signals are conveyed from one part of the nervous system to another are now much better understood than before, but our fundamental ideas about them remain as described in this book. Much the most difficult part of the subject is the study of how these impulses are initiated by the dendrites and nerve cell bodies and here, unfortunately, there has been only a modest advance. We still do not know in fact how the nervous system puts information into a code for transmission. Possibly a change is under way in this respect, and recent work on the properties of the dendrites of cells is giving us a new view of nervous activity.

In considering the function of the various parts of the brain there is also a continual increase of knowledge from year to year. We can now describe the effects of removing many parts of the brain in some detail. Unfortunately, this alone does not give us all the information that we need to be able to correct aberrations of the workings of any part.

A good deal of the book is devoted to discussing the nature of the memory store. Here once again there has been some progress, but we are still ignorant of exactly what change is involved in the cells as learning takes place. Our own work on octopuses, which has been directed to this subject, has proceeded during the last ten years, but we are only now beginning to be able to trace the outlines of the model in the nervous system that corresponds to the situations that the animal has experienced. However, at least we have shown, and for the first time, that the arrangement of the processes of the cells corresponds to the vertical and horizontal lines along which shapes are analysed by these creatures. We know, therefore, that there *is* a model in the brain, at least of these animals, corresponding to the outside world.

Understanding of the process of human communication of language also proceeds slowly. Since this is unfortunately outside my own field I am not able to follow all of its modern developments. It will evidently be a very long time before a generally accepted theory of the origin of language is developed. The use of computers for translation, among many other functions, is providing us with an analysis of language, which is at least novel and effective in its own performance; although it may seem brutal to those with more traditional views. The possibilities of using computers to imitate human brain functions are constantly expanding. In some respects we can say that we have computers that read, translate, and even think. And yet, to many people it seems that there is still an enormous gap between the performance of these machines and that of a human being. That there is such a gap is indeed true, and it resides partly in the fact that whereas the machine proceeds with extreme logic and great speed, the calculations of the nervous system proceed with, as von Neumann has put it, much less arithmetic and logical depth. In order to produce the answer to a simple sum, say four times four, the brain does not proceed through the entire sequence of logical operations involved in multiplying, as a computer would have to do. It reaches the answer by some other method, which may be briefly called 'analogical.' We still do not know how it does it but at least, by comparison with digital computers, we begin to find a language for discussing the problem.

It is an interesting question how much the development of computers is likely to be helped by studies of the brain. Up to the present engineers have proceeded mainly on their own lines in construction of both digital and analogue machines. The principles now being discovered at work in the brain may provide, in the future, machines even more powerful than those we can at present foresee. However, there are some very severe difficulties in making a model whose working depends upon the presence of an enormous number of parts, each pre-set to respond in a particular way. Some such system as this may be involved in the brain, with the added complication that the parts are not unchangeable but can be modified with use. To make a machine on these principles will certainly tax the ingenuity of the engineer. First it must be demonstrated that this machine could achieve results unobtainable by the more precise, if limited, operations of an orthodox calculating machine.

A part of this book is devoted to the study of human society as seen through the eyes of a biologist. Of course this is a field for specialists and the view given here is essentially that of a layman. So far as I can discover there has not been any spectacular development in theoretical or practical approaches to such problems since the book was written. This is indeed particularly disappointing when we think of the tremendous importance of the subject. The attempts at interpretation in the book are so primitive that they make me blush; nevertheless, they are perhaps worth attention if only as an example of how one discipline might be able to co-operate with another. I have not noticed that any suggestions I may have made have had much effect on those working in the subject except perhaps to irritate them. Many, however, have written to express their interest in this point of view, which encourages me to think that the biologist's training provides something that may be of value in other disciplines besides that strictly regarded as his own.

In fact, in spite of much criticism, I remain unrepentant of the thesis that the biological method of study should play a central part in all studies of man, and in particular that investigation of the brain is among the most important of all human enquiries.

J. Z. YOUNG

August 1959

PREFACE

THE REITH LECTURES for 1950 are here printed as they were given, with only the alterations necessary to make reading reasonably smooth. In preparing the lectures I was aware that the information was often unduly concentrated and that it needed amplification. In order to provide this without interfering with the individual lectures themselves, I have therefore added five chapters of comment, placed between the lectures. I hope that by reading directly through the book, including these comments, the reader will get a complete view of the thesis.

After much deliberation I have decided not to add a comment to the last lecture. There is obviously very much that could be said to expand the attempt to forecast the effects upon society of these new ways of speaking. I am much tempted to do it, but am very conscious of the great dangers that face the biologist if he tries to turn sociologist, without prolonged study of the enormous and diffuse problems that are involved.

There is plenty of evidence that scientists make foolish statements when they try to speak or write for large numbers of people. I have been most painfully aware that my language has not always been effective or even consistent, and I fear that theologians and philosophers in particular will dismiss much of what I have to say as simple-minded, because it is not written in the usual idiom of their systems. However, scientific language changes year by year. Scientists believe that they must doubt even the apparently most fundamental laws. Is it possible that there are significant aspects of language that even philosophers have not yet discovered? The scientist would not be surprised to find that it was so. Indeed, he would be suspicious of anyone who claimed that the last and best word on *any* subject had already been said, by Plato or anyone else. Let us praise famous men and their works, by all means, but a still more important duty is to improve on what they have done. We can look back with pride at human achievements, but surely everyone looking at the difficulties that still face mankind must feel that we should try to improve even further on the system of communication provided for us by philosophers, theologians, and scientists.

The way of speaking used in these lectures is that of a biologist reared in the tradition of study of evolution, of anatomy, and of physiology. It would be impossible for me to trace out in a short space even the major writers who have influenced me in arriving at this position; the discerning eye will detect them soon enough. I have followed the tradition of empiricist philosophy, through A. N. Whitehead, to the modern British exponents, especially Ayer and Ryle. The application of such methods to psychology and the study of behaviour comes from William James, J. Loeb, J. B. Watson, and K. S. Lashley. If there is a special contribution in these lectures it is perhaps in allying these methods with those of the anatomist, physiologist, and evolutionary biologist. My sources here are the whole tradition of British Zoology, especially as expressed in the work of E. S. Goodrich and D'Arcy Thompson, who in their differing ways called attention to the study of living form. In recent years we have learned new ways of speaking about how living organization evolves, through the study of populations by J. B. S. Haldane, R. A. Fisher, and many others. L. Hogben has shown how such biological methods can be applied to a wide range of human affairs.

It would be impossible to mention a fair sample of the studies that make up even the background of our knowledge of the nervous system, around which the whole thesis of the lectures is built. Sir Charles Sherrington's contribution is evident throughout and a similarly pervasive influence is that of E. D. Adrian's studies of so many aspects of the electrical activities of the brain and nerves. It is not perhaps generally realized how greatly all such work depends on exact description of the detailed structure of the cells of the brain, as was given by Ramon y Cajal, and of the network of tracts of fibres that connect the parts, to which W. E. Le Gros Clark has recently added so much.

Many new ideas are now being contributed to the study of the nervous system through the interest of mathematicians and engineers, such as A. S. Turing, and N. Wiener. I hope that the force of their contribution is felt in the text, though I have not been able to use their symbolism.

The quotation of sources for general scientific theory is an absurd as well as invidious business. Much is contributed by a few great initiators, but the body of scientific knowledge is made up of the vast mass of detail provided by many individual workers. It is this body of detailed knowledge, freely available, that makes science a valuable agent for use by all mankind.

I owe a very great deal to the stimulus I have received from interchanges with many colleagues in London and Oxford, some of whom were good enough to read part or all of the script. H. Dingle, A. J. Ayer, T. D. Weldon, D. Forde, E. A. Blake Pritchard, D. Sholl, F. Roberts, helped especially in this way. I often foolishly neglected their advice, but whére I have taken it the text has become very much improved. I owe a special debt to Mr. Brian Boycott for his assistance with the experiments on the octopus—indeed it was he who performed nearly all of them. Much scientific work nowadays depends on skilled technical help, and I should like to thank the technical staff of the Department of Anatomy at University College for all they have done in this respect, and especially Mr. F. J. Pittock and Mr. J. Armstrong, for the beautiful microscopic preparations and photographs made under their direction. The scripts of some of the lectures ran through as many as six versions, and I am very grateful to Miss P. Codlin and Miss M. J. West for their patience over preparing these. Miss E. R. Turlington drew the line-drawings with her usual skill.

If the lectures were understandable when delivered it was mainly due to Mr. R. Lewin of the B.B.C. who advised me

throughout. Had I taken his advice more often they would have been clearer still. The British Public is to be congratulated on having a Broadcasting Service that makes available such intelligent, competent, and patient production work to assist its speakers.

J. Z. Y.

June 1951

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First Lecture

THE BIOLOGIST'S APPROACH TO MAN

When I was asked whether I would consider undertaking the Reith Lectures, I said that it might be possible to give some idea of the methods of science by describing the various sorts of work at present in progress on the brain. Frankly I did not consider that this would be a piece of research. The scientist does not usually think of the writing of books or preparing of lectures as research. Writing seems to him to be a rather tiresome labour that he must do after the fun of laboratory research and discovery is over. I therefore sat down to use the time available more in hope of making a summary than a discovery. But when I began to do this I came to realize the extent to which having to describe the results of one's thoughts to others is a part of the process of discovery itself. We are social creatures, depending far more than we realize on communication with each other. We can understand better both the workings of the brain and the nature of scientific inquiry itself if we realize how deeply our whole life is influenced by this necessity of communication. Paying attention to this fact has made me think in a way that is new and helpful to me, and I hope may be so for others also.

One of the characteristics of scientists and their work, curiously enough, is a certain confusion, almost a muddle. This may seem strange if you have come to think of science with a big S as being all clearness and light. There is indeed a most important sense in which science stands for law and certainty. Scientific laws are the basis of the staggering achievements of technology that have changed the Western world, making it, in spite of all its dangers, a more comfortable and a happier place. But if you talk to a scientist you may soon find that his ideas are not all well ordered. He loves discussion, but he does not think always with complete, consistent schemes, such as are used by philosophers, lawyers, or clergymen. Moreover, in his laboratory he does not spend much of his time thinking about scientific laws at all. He is busy with other things, trying to get some piece of apparatus to work, finding a way of measuring something more exactly, or making dissections that will show the parts of an animal or plant more clearly. You may feel that he hardly knows himself what law he is trying to prove. He is continually observing, but his work is a feeling out into the dark, as it were. When pressed to say what he is doing he may present a picture of uncertainty or doubt, even of actual confusion.

This mixture of doubting with the certainty of scientific laws is not a new phenomenon. We had a chance recently to see it stretching over three whole centuries in the celebrations of the third centenary of Newton's birth in 1642. The Royal Society asked a number of learned men to write about Newton. Some placed great emphasis on the fact that Newton would not speculate 'beyond the limits where quantitative confirmation could be sought from nature'. They quoted Newton's famous remark, '*hypotheses non fingo*'—'I do not make hypotheses'. By this he meant that he only derived laws from observations of nature, a process that he considered to be distinct from framing an hypothesis as to the causes of the phenomena. Those who are attracted by this side of Newton's character emphasize his constant work in the laboratory, how he made his own mirrors, his own experiments with light, and endless other matters. He was one of the most exact, practical, and knowledgeable persons who has ever lived. 'I do not deal in conjectures', he himself said. Evidently for some people this is the typical picture of a scientist. But wait a minute. When Newton said that he did not deal in conjectures he was eighty-one years old. Other learned men investigating his writings have proved that what he said about himself was not true. He *did* make hypotheses and conjectures; from his young and most fruitful period onwards he made them endlessly. Some of them were very good hypotheses—Newton developed a general theory that matter is made of atoms. We can hardly make a better one today. But he could not prove it; he could neither see the atoms nor detect the forces that bind them together, as we can do now. His theory was therefore a sort of guess—a conjecture. He made another guess about an aether that pervades all space. And he puzzled over much more curious matters than these. He spent a great deal of time studying the writings of mystics, theologians, and alchemists. For weeks on end he worked in his laboratory making experiments to find the philosophers' stone that would turn lead into gold. He left a mass of writing on these magical and alchemical subjects, writings so diffuse that they have never been published. The late Lord Keynes, commenting on these papers, suggested that Newton was not so much one of the first men of the age of reason as the last of the magicians. He seems to have thought of the universe as a riddle posed by God, which could be solved if one looked hard enough for the clues. Some of the clues were to be sought in nature, others had been revealed in sacred and occult writings. The search for the answers was a continual struggle and anxiety, and it drove Newton to the edge of madness.

The point for us is that Newton did not spend his time simply observing nature. Besides doing that his brain also tried to put all the observations together, to fit them into general schemes. This search is the process that I call doubting. It is a process of exploration, and when significant resemblances are found we say that a new law has been promulgated, that some degree of certainty has been achieved.

What I hope to be able to demonstrate is that this mixture of doubt and certainty is not at all an accident. It is the very nature and essence of scientific method. Moreover, it is not by any means a character peculiar to science. Science is only the latest product of the human brain, which has been working in essentially the same way for the last 10,000 years: that is to say for the period of our history as a social animal.

Still the matter does not end there. This method of proceeding is but a development of the way in which all brains work. Indeed, I shall try to show that there is something corresponding to the discovery of certainty through doubt in all the operations of living things.

This is a formidable task, and I became conscious as I proceeded of how much one needs to know of history, psychology, anthropology, mathematics, and many other things. But to be able to see in perspective the range of phenomena from the nature of human thinking and scientific inquiry to the facts of evolution (and perhaps even of cosmology) would be such a clarification that it is worth the attempt. I feel that I have made some progress in this direction, and cannot do less than ask you to share the results, taking what may be wrong with anything that is right.

The method I have followed is simple enough. I have looked at man as a modern biologist looks at plants and animals. How do biologists work and what language do they use to describe their view of the world? We might say that they examine how each sort of animal and plant manages to keep its kind alive. Every creature maintains its organization distinct from the surroundings: it prevents itself from returning to dust. Biologists study how even the humblest plant is a wonderfully organized system of roots, stem, leaves, and flowers arranged to do this. These parts all act together to extract from the simple materials of soil and air the means to build the plant and propagate its kind. In animals, similarly, the various parts act together to nourish and protect the organization and enable it to continue.

The biologists' question about man is, therefore, how does he get his living on the earth? What are the means by which the continuity of human life is ensured? In answering it some biologists might say: 'Man is an omnivorous, terrestrial, bipedal mammal', or some such talk. I believe that such phrases show where we biologists have all been wrong. We have been concentrating on those features of man that are obviously like those of animals; his digestion, his locomotion, and so on. We have been very much more loath to realize that we can apply the same methods also to his higher functions. Eating and walking are not the really important features of man. We all recognize that it is far more significant that he is, shall we say, a thinking creature, or a worshipping one. What we have not sufficiently considered is that it is just these traits of what we commonly call man's mind that are also his most peculiar and important *biological* characteristics. These are the features by which he gets his living: they are the very ones that should most attract our attention as biologists.

Each animal has some special ways of conducting its life. The cow and sheep have special stomachs that digest grass. The tiger has its teeth, the elephant its trunk and its teeth, and so on. What then are the special characteristics of modern man? Surely the chief one is that of co-operation between individuals. Man's large brain is used to develop an intricate social system, based mainly on communication by words. Man has many other special features, such as good eyes for getting information, and good hands for doing intricate things. But it is chiefly co-operation that enables him to obtain a living for more than 2,000,000,000 human beings scattered over nearly all regions of the earth. Sophocles expressed it long ago in a few words when he said: 'Of all the wonders none is more wonderful than man—who has learned the arts of speech, of windswift thought, and of living in neighbourliness.' These are indeed the matters that must chiefly engage the serious student of man. Of course on this subject of human co-operation a vast mass of knowledge has been collected by generations of anthropologists, psychologists, sociologists, and others. But there is, even yet, no coherent body of knowledge about the biology of man that sets him in his proper place in the living world. Biologists are only now beginning to study what may be called the higher attributes of man, his language, his social behaviour, his religion, and his science. We may find valuable new ideas by