MODELS: THEIR USES AND LIMITATIONS

by

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1/ Since most of the notions discussed here are byproducts of my collaboration over the past several years with Allen Newell, I have asked him to permit me to present this paper as a joint product--which it is. For infelicities of form and manner, and for downright errors, I alone am responsible. HAS

In contemporary usage, the term "model" is, I think, simply a synonym for "theory." I am to speak, then, on "Theories: their Uses and Limitations." This is a topic I can handle very briefly: the uses of theories are obvious, and their only limitations are that they are often bad theories.

At this point, the persons who arranged this meeting may well cry, "Foul!" Clearly, they intended the entertainment to last more than one minute; and presumably they did not intend that "model" should mean simply "theory." I suspect--but it is only a suspicion--that by "model" they meant "mathematical theory", and they intended to exhibit in this arena another installment of the prolonged guerilla warfare between mathematics and language.

With respect to these hostilities, I have two comments. First, I stand with J. Willard Gibbs: "Mathematics is a language."--and to my ear, the most dulcet of languages.

Second, I do not believe that the form in which we clothe our thoughts is a matter of indifference—or even of taste, as my last comment may seem to imply. It may be true that words without thoughts

never to Heaven go; but the converse is also true: wordless thoughts,, too, are earthbound. The matter has been put very well by Roget, the author of the Thesauras. In the Introduction to his work he has this (as well as many other wise and even profound things) to say:

> "The use of language is not confined to its being the medium through which we communicate our ideas to one another; it fulfills a no less important function as an instrument of thought; not being merely its vehicle, but giving it wings for flight. Metaphysicians are agreed that scarcely any of our intellectual operations could be carried on to any considerable extent, without the agency of words. None but those who are conversant with the philosophy of mental phenomena can be aware of the immense influence that is exercised by language in promoting the development of our ideas, in fixing them in the mind, and in detaining them for steady contemplation. Into every process of reasoning language enters as an essential element. Words are the instruments by which we form all our abstractions, by which we fashion and embody our ideas, and by which we are enabled to glide along a series of premises and conclusions with a rapidity so great as to leave in the memory no trace of the successive steps of the process; and we remain unconscious how much we owe to this potent auxiliary of the reasoning faculty."

If we interpret the term "word" literally, then Roget is probably wrong. But if he means that the form of our thought exercises a great control over the course of that thought, he is almost certainly correct.

To select a suitable language with which to wing our thoughts, we must understand what languages there are, and we must be able to compare them. In this paper, I should like to discuss three main kinds of scientific languages or theories—the mathematical, the verbal, and the analogical. It will appear from our analysis that these three kinds of theory are really closely alike in most of their important logical characteristics; hence, that the choice among them must be based on certain pragmatic or psychological criteria. And since analogies, employed as theories, are somewhat less well understood than either ~~verbal or mathematical theories, I shall devote the last part of the paper to two important current uses of analogies.~~

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Before we can plunge into the comparison, however, we will need a clearer understanding of the nature of theory, and of these three types of theory in particular. The next two sections will be devoted to these preliminaries.

Models and the Modelled

By the content (or total content) of a theory I shall mean the totality of the empirical statements that the theory makes, explicitly or implicitly, about the real world phenomena to which it refers. That is, the content of a theory is comprised of all the assertions about the world, whether true or not, that are explicitly stated by the theory or that can logically be inferred from the statements of the theory.

Consider now some body of phenomena, and imagine that there is a theory that tells the truth, the whole truth, and nothing but the truth about these phenomena. By this I mean that any statement that is true of the phenomena is stated in or derivable from the theory; and that any factual statement contained in or derivable from the theory is true of the phenomena. Then we may define the content of the body of phenomena as identical with the total content of this particular theory.

The particular theory I have just mentioned is, of course, non-existent for any actual body of phenomena. The theories that actually occur do not have the same content as the phenomena to which they refer. They do not tell the truth--or at least they do not tell the whole truth and nothing but the truth.

Conclusion: Science as Analogy

The basic postulate underlying this discussion has been that, contrary to general belief, there is no fundamental, "in principle" difference between theories and analogies. All theories are analogies, and all analogies are theories. But two theories are not equivalent for the scientist simply because they have the same total content. The choice between theories depends critically on the ease with which their logical content can be extracted by the manipulations of information-processing systems operating upon them, and the ease with which errors of omission and commission can be detected and avoided. This is the real core of the debate about the relative virtues of mathematical symbols and words as materials of theory.

We must not suppose, simply because verbal and mathematical theories have been with us a long time, that methodology is a static matter--an unchanging substratum for the changing substance of science. Methodology requires a reexamination today, both because of the novel substantive problems that the behavioral sciences face and because of the novel devices that are now available to help us solve these problems.

A theory of man that takes account of his characteristics as an information-processing system is just beginning to emerge. Already, the theory suggests a system exhibiting a degree of complexity with which the sciences--and certainly the behavioral sciences--have not hitherto dealt. Modern electronic computers have been, and continue to be, an important influence, by way of analogy, on the emergence of this theory. If the argument advanced here is correct, these same computing devices may provide us with the materials for a methodology powerful enough to cope with the complexity of the theory as it emerges.