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RELATIONS BETWEEN PSYCHOLOGY AND OTHER SCIENCES

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CONTENTS

Psychology occupies a key position in the family of sciences in that it depends upon each of the others, to different degrees, and in turn it illuminates them all in distinct ways.

PSYCHOLOGY AND BIOLOGY

In the relations between psychology and biology these two-way exchanges are particularly striking. It might seem that psychology was completely subordinated to such sciences of organic life as physiology, studies of epigenesis and genetics (extending to analysis of the genome). But we now know well that there is much feedback from behavior to details of organization of the brain and nervous system (see among others the research of Rosenzweig, Krech and Bennett; this and related work is reviewed in the

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chapter by Hunt in this volume). Psychosomatic medicine shows the existence of even more extensive interactions. Ethology is a branch of both psychology and general biology. As to heredity, it is not clear that its mechanisms are exactly the same for transmission of purely morphological characteristics (a color, the form of a particular organ, etc) or for the formation of general organs that condition behavior (locomotion, etc). We know now that behavior is not simply a result of evolution but is one of the factors that govern evolution. I have in fact written a small book—rather speculative, it is true—to argue that behavior actually is the main driving force behind evolution. It therefore seems probable that the better one knows these connections, the greater will be the influence of causal explanations from psychology on the interpretation of the central mechanisms that biology studies. In turn it seems evident to me that if contemporary psychologists had more knowledge of biology, there would be fewer partisans of pure behaviorism, and Skinner's "black box" would be furnished with more fruitful hypotheses.

PSYCHOLOGY AND LOGICO-MATHEMATICAL DISCIPLINES

While psychology thus seems to depend on biology and also reciprocally to illuminate some parts of biology, it might at first seem that no direct relation links our modest science, which is so young (begun scarcely more than a century ago) and still weak in substance, to the imposing mass of the logico-mathematical disciplines which are so rich and solid. At the most one might say that the psychologist seeks to be as logical as possible in his reasoning and that he borrows some formulas from the theory of probability when he does his statistics. In a word, compared to mathematics, psychology seems like a youngster and scarcely related to the mature giant of the logico-mathematical disciplines which dates from the origins of our scientific civilization (from Greece and the Orient) and which enjoys complete autonomy. It is, for example, inconceivable that a mathematician would consult a psychologist to see whether a new theorem that seems to have been proved is truly valid as to its intrinsic content.

Nevertheless, when one studies the psychogenesis of structures of the intellect, as we have attempted to do in children, one perceives the startling fact of an undeniable convergence between them and the most general structures that the mathematicians are creating. For example, the structuralist school of Bourbaki, to cite living authors, has attempted to reduce the ensemble of presently known mathematical structures to elementary and universal forms which they call "mother-structures" and from which all others can be derived by differentiations or combinations. The three "mother-structures" are the following: (*a*) the algebraic structures with their reversible operations, (*b*) the structures of order, and (*c*) the topological structures (regions, boundaries, etc). Now it happens that before hearing of the work of the Bourbaki school, we had found that the earliest structures achieved by the infant (in the sense of what he can do and not what he thinks or says, which come much later) are these: (*a*) elementary operations dealing with classes and their nesting (union and exclusion), that is, algebraic structures in the sense defined just above; (*b*) ordinal structures that govern relations, for example, in the elementary construction of seriations; and (*c*) topological structures based on regions, enclosures, and boundaries, etc.

This convergence between the abstract structures created by mathematicians and the elementary and very concrete structures formulated by the infant thus shows that the former, as theoretic as are the considerations that governed their construction, are nevertheless "natural" structures in the same sense that we speak of "natural numbers" for the integers 1, 2, 3, 4 . . . that each youngster discovers by combining algebraic structures with those of "orders." These "natural" structures thus have roots that go much deeper than those considered in the thematic thinking of scientific mathematics. It follows from this evidence that the roots of mathematics are to be sought in the spontaneous cognitive activity of the human subject, even one who is young and innocent of any scientific thought.

Since such a subject and his cognitive activity constitute the specific concern of psychology from the psychogenetic viewpoint, it is not an exaggeration to say that it is up to psychology to explain to us the formation of elementary mathematics and that, in this sense, if one is not a Platonist or dominated by an a priori philosophy such as that of Kant, there is a linkage, not of course between higher mathematics and the psychogenesis of early behavior, but between the source of logico-mathematical structures and the constructive activities of the subject who is studied by developmental psychology. This is true in the case of the "correspondences" or "morphisms" studied theoretically by McLane and Eilenberg following the Bourbaki school and their elementary forms that the child of 7 to 12 also constructs. (The correspondences employed by Cantor were already known to children well before this great mathematician promoted this concept to the rank of a theoretical instrument.)

What we have just stated demonstrates that the source of mathematics is certainly not psychology but rather the *person* that psychology studies. On the other hand, the *epistemology* of mathematics needs psychology and is based largely on it. Now the epistemology of mathematics is a part of mathematics known by the name of theory of foundations, and this necessarily combines logical considerations with those furnished by the study of psychogenesis. In this sense, psychology plays an indispensible role in the initial or metamathematical sectors of the logico-mathematical disciplines.

There is a fundamental problem of mathematical epistemology to whose solution psychology makes an indispensable contribution. This is the basic question of why mathematics fits so well with physical reality. This is a problem on the biological level concerning adaptation of the organism to the environment, but it is even more profoundly a psychological question since it deals with the possibilities of adaptation of the intellect itself. We find only a single reasonable response to this difficult question. This is that the subject who can be considered to be the creator of logic and of mathematics is also and at the same time one material object among others. He is a physical object not only in terms of his organism but just as much in terms of the physical actions that he exerts on objects (grouping, ordering, etc). Consequently, when he constructs logico-mathematical operations, he does so by extending the material actions that he executes as a physical organism. In a word, the agreement between mathematics and physical reality is accomplished within the physiological organism or by its instrumentality and not only by means of the poor and scanty empirical verifications furnished by its initial actions. So here is a further proof that if mathematics is not derived from psychology, its source is in the activities of the individual who is a physical entity in the form of an organism already highly adapted and intrinsically structured and made known through psychology.

PSYCHOLOGY AND HUMAN SCIENCES

Linguistics

Relations between psychology and human sciences should be simpler than those considered above, but actually they are rather complex because here they are no longer links but rather intersections. To start with linguistics, we know that earlier linguists of the generation of de Saussure did not want to have anything to do with psychology, believing that language as a social institution forced itself on all individuals regardless of their personal characteristics. It took the "Cartesian linguistics" of Chomsky to make people see that intelligence is not subordinated to language but that the inverse is true. But the psychology of Chomsky and his school remains rather impoverished; instead of placing language among the self-regulatory mechanisms where all the cognitive processes belong, he called upon a "fixed innate core," as if it would simplify the problem by throwing it back to biology. Actually, deriving language from sensorimotor intelligence raises many very interesting questions and ones to which it is already possible to offer answers that can be tested experimentally. In any case, the existence of psycholinguistics and especially its psychogenetic forms is a pledge of collaboration that is full of promise.

Economics

Relations between psychology and economic sciences also show partial collaboration and once more in the form of intersections rather than links. Let us limit ourselves to two examples, both of which are rather instructive. The first is impressive in furnishing a method in common and one that can also be stated mathematically; this is the invention by Morgenstern and von Neumann of "game theory," which makes it possible to calculate the strategies best adapted to optimalizing successes in competitions between opponents. Shortly after it was inaugurated in the economic domain, this method was tried out on certain psychological problems; here it showed itself useful even in questions far removed from economic conflicts, such as interpretations of perceptual phenomena. In general one can consider the following as contestants in a game: on the one hand the occurrence of psychological and even physical events (that is, the succession of phenomena as objects of study), and on the other hand the observer who tries to anticipate them and to explain the reasons for his successes and failures.

Another point of convergence between psychology and economics comes this time not from a method of calculation with its decision tables but from attempts to extract a general theory of action. Under the name of "praxeology," certain authors (Kotarbinski and others) have tried to analyze the general conditions that permit effective action. While some economists have criticized this theory as too general or too abstract to be used in economics, others have claimed that this is the basis needed for all economic analyses. It is certain that if these concepts attain the necessary level of precision (and this is still debated), they will be of great interest to psychologists. Since we have sought to find in action the source of all cognition, we will be particularly interested in the success of this enterprise.

We will not consider in this paper the possible influences of Marxist economics on psychological research, because that would take us too far afield and especially because we would be confronted with the problem of carefully disentangling the not inconsequential role of ideologies from what is fertile in all dialectical methods. But since this problem is much more general than the relations between psychology and economics, it would not be prudent to go into it here.

Sociology

If the connections and conflicts between psychology and linguistics or economics are a matter of course, one might suppose that this would be true *a fortiori* between psychology and sociology. It is extraordinary that the latter relations have remained up to now much poorer than the former ones, an exception being the work of the eminent intellect Talcott Parsons. This poverty is certainly due to the sterile disputes aimed at determining to what extent the action and thought of people are based on social factors and to what extent they are due to individual initiative. Now since every person is socialized, even the most solitary of researchers, and since every society is formed of individuals who have nervous systems that are not due to social life, along with the continuous functioning that the nervous systems afford, it should be clear that the real problems lie on a different plane. An approach is suggested in the cognitive domain where we see in the history of science the impressive number of cases of simultaneous but independent discoveries—Newton and Leibniz in the case of the calculus, Darwin and Wallace for evolution through natural selection, and so forth. In such cases it seems that the Zeitgeist functions as a sort of common regulatory system acting at a level that transcends both the social and the individual. The nature of this influence deserves to be analyzed further, but this is not the place for me to attempt to do so.

PSYCHOLOGY AND CYBERNETICS

To return to verifiable hypotheses, let us now consider relations between psychology and the still young but highly promising discipline of cybernetics. This is essentially a theory of teleonomic models that deal, for one thing, with relations of means to ends, for another, with regulatory modulations (positive and negative feedbacks, as exemplified in the chapter by Miles and Evarts in this volume), and generally with the acquisition and transmission of information. As such, cybernetics pertains to all biological and psychological processes as soon as they go beyond simple direct causation. While cybernetic models can be relatively simple when they deal with circumscribed cases of regulation, they become complicated when they reach autoregulatory systems (regulation of regulation) and when they take up problems not yet entirely resolved of the origins and especially the modification of programs. The more complicated are the phenomena to be explained, the more the relations between psychology and cybernetics become interchanges and mutual enrichment. For one thing, cybernetic models afford explanations in domains where earlier thinkers saw only two types of solutions that are now out of date. One was an excessively simple reduction to pure mechanism, in imitation of physics, thus eliminating all purposive or goal-seeking aspects; the other was an equally unfounded vitalism calling, as did Driesch, on "entelechies" or other imaginary metaphysical entities. Cybernetics has thus enriched biology and psychology with new models that make possible interpretations based on equilibria that improve, that is, moving to higher level equilibria and not just returning to the starting point. On the other hand, biology and psychology often supply cybernetics with factual examples that call for more and more complex models of self-organizing systems which can then be studied by simulations (see, for example, the discussion of information processing and of "artificial intelligence" in Simon's chapter in this volume); this affords an enriching stimulation to cybernetic theorists.

PSYCHOLOGY AND PHYSICS

This leads us at last to examine relations between psychology and physics, the domain where at a glance it seems that relations are the most impoverished. But we should start by noting a profound statement made at the start of this century by the great physicist Charles Eugene Guye (the first investigator to have verified experimentally a relativistic prediction of Einstein). Guye maintained that physics is not yet a truly general science since it remains artificially limited to the study of inert matter; he claimed that a complete physics would also study living beings and especially thinking ones. His hopes with regard to living beings are being realized since we now have both biophysics and biochemistry. With regard to the physics of thought we still know nothing. Guye hypothesized that thought might occur through subatomic physical reactions; this is clearly a daring hypothesis but perhaps not impossible.

While awaiting a possible physics of thought, we can point out two kinds of help that psychologists can furnish to physicists and, indeed, to all scientists. The first is to emphasize that what we call an observation is never a pure observation because it always and everywhere implies an interpretation which constitutes a necessary frame of reference, either implicit or inferred. To say, for example, that an object occupies a particular location requires a set of spatial references. To say that it bumps into another object requires certain preconceived ideas about the nature of the collision. When microphysics teaches us that a phenomenon always depends on the reactions of the observer as well as on the object observed, that is true at all levels, and we can note further that the more closely the observer approaches the object, the more the object seems to retreat by becoming more complicated and by raising new problems. This in no way excludes progress in conquest of the object, but it occurs through successive approximations and is never completely achieved; there is always a limit in the mathematical sense. This is not philosophical idealism because the object exists before it is known and it conserves its properties independently of us while it is being explored by experimentation. But the exploration cannot be reduced to a pure "reading" of observables; there is always a contribution of the observer who interprets what he sees, even if he is not aware of interpreting. Nor is this a theory of Kantian noumena, because the apparent object of intuition keeps changing into new phenomena as it is studied experimentally.

A further service that psychology can render to other sciences is to supply a theory of causal explanation. Establishing a law is not an explanation but only the simple generalization of observations without supplying the reason behind them. This is still true when a particular law is subsumed under a more general law; the latter still remains classificatory and alien to reasons. Explanation, on the contrary, implies the construction of a model and elaboration of the model by operations available to the investigator. But he can use these operations in two ways. The first consists simply of applying them as tools of description or measurement; in this case the researcher does not go beyond the reading of observations and still does not attain an explanation. Explanation begins only when the operations are not simply applied but are "attributed" to objects in the sense that these then become "operators" and this permits one to understand how they interact. The clearest and most common example of this is that of the structure of a group when this is attributed to an organized set of phenomena and when their transformations and interactions are taken as the expression of a group located or projected into reality. Thus current microphysics continually uses an ensemble of groups and operators that are attributed to objects and that explain their varied behaviors. The models are constructed by means of operations of the investigator but the models consist in finding these operations at the heart of the phenomena that are to be understood. So that we are no longer simply describing observables but attaining the reasons for the laws in considering constructions that are both objective and outside of ourselves but that we can understand thanks to their analogy with our logico-mathematical structures. A group is, in fact, a system of transformations, and if we project it into the real world we can therefore penetrate to the causal transformations of the world.