THE ROLE OF INTUITION IN THE SCIENTIFIC METHOD

Nicholas M. Smith
Research Analysis Corporation

ATSTRACT. By virtue of Huygens' careful appraisal of the Newtonian method of inquiry, a logical fallacy has long been detectable in Newton's contention that he had deduced truth from observations of nature. The logical fallacy is concerned with two aspects over which empiricism has no control: (1) the observation that what constitutes a fact in the test of a theory is not determined by empirical principles alone, and (2) the observation that the constructs of science cannot be demonstrated to be other than sufficient with respect to the so-called facts. The necessity--that is, the uniqueness--of these constructs can never be established. The realization has gradually emerged that whatever is "true," "valid," or "warrantable," is not to be determined by absolutely singular discoveries produced in flashes of insight, but by selection among alternative creative insights on the basis of systematic tests constituting the reasoning process. The possibility of alternative insights of equal predictive applicability makes necessary the imposition of some principles other than empirical ones to decide among them. These principles are intuitive and categorical. That is, there exists a set of cognitive controls (of which empirical tests are members) which are established for the sole purpose of preventing ambiguity. Some of these principles have appeared in modern and contemporary science, notably the principle of relativistic invariance, which can be traced directly to the need of preventing procedural ambiguity introduced by transformations. There are other important introspective controls which delimit forms acceptable for application in the cognitive act. Many of these introspective principles are to be found separately in contemporary theories of value. We have formulated a theory of these cognitive controls based on our attempts during the past two years to establish the foundations of a rational methodology for systematic and organized prescriptive activities, that is, the decision process in all its generality. Science, as a decision system which has as its purpose the production of predictive theories, is shown to be a reduction of the more general axiologies. Consequently, many of the important so-called laws of science are not singular discoveries of properties of the external world entirely, but are in addition necessary properties of admissible forms which may serve as objectifications for applicable symbolic scientific models. Among these principles may be some of the most cherished scientific discoveries: the relativistic properties of space-time, the conservation of momentum, the conservation of energy, the second law of thermodynamics, and the Heisingberg uncertainty principle.

INTRODUCTION. The purpose of this discussion is to present the findings of a study* conducted at the Research Analysis Corporation for the past several years concerning the nature of the rational or cognitive process. This study has revealed that intuition (or introspection, as we shall call it) plays a much greater role in the process of rational thinking than we had heretofore suspected. The nature and complexity of the subject is such that a detailed presentation in a systematic and convincing step-by-step procedure would require many hours. We shall therefore resort to a presentation of our material in the time available in the form of an elaborate abstract. It cannot be hoped that such a shortened version of our presentation can be wholly convincing. It is hoped, however, that the attention of the reader will have been directed to some shortcomings in prevalent notions of the scientific method as applied to the design of experiments. We also hope that our method of resolving these problems will seem plausible and that your own interest in this exciting field will be aroused.

The study I am describing has been motivated by a search for the foundations of management science. In the term "management science" I mean to include such other terms as operations research, operations analysis, industrial engineering, economics, and the like. Those who practice these professions are not in complete agreement as to a statement of their mission; but in general these ingredients will be found in any definition: management science is somehow to provide a client with aids--quantitative or otherwise--to one of his decision processes. Or, the analyst may even go so far as to recommend specific decisions to the client. These aids, or these recommendations, are formulated with respect to the client's value system; it is further claimed, either implicitly or explicitly, that the management scientist employs a method which will somehow lead to better decisions. These definitions are charged with highly significant but poorly defined words. These words are "decision," "values," "method" and "better." The search for an understanding of the ideas behind these words has triggered an escalade of theoretical projects.

In the first place we have committed our interest to the field of practical decisions and therefore have become interested in the theory of decision algorithms. To many persons who practice our profession this subject may appear as the sole content of management science. This general field covers such divisions as mathematical programming, queueing theory, logistics theory, game theory, etc. The central commodity in terms of which decision

* This paper describes work done under RAC Study 5.4, "Valuation and the Cognitive Process," by N. M. Smith and M. C. Marney.

makers operate in reaching their decisions, however, is value. Since values are the determinants of decisions, a whole new theoretical field in the theory of value is developing. Value theory, on the other hand has drawn attention to the decision process in context of system. One cannot understand the act of evaluation without understanding the nature of the system in which the evaluation process is undertaken. This situation thus leads to a third theoretical project--the theory of selective systems.

Finally one must turn to the question of the validation or warranting of values, policies, and ethical systems. The question of such warrant, together with questions concerning the adequacy of the methodology of professional management scientists, have drawn out interest into the general theory of cognitive processes.

RECONSTRUCTION OF PHILOSOPHICAL FOUNDATIONS. The first impediment one encounters in the search for a method of warranting a value-decisions process (or, as we shall call it, a prescriptive process) is the conculsion that contemporary scientific method is inadequate. This inadequacy arises because one of the chief controls in the scientific method is a predictive process. One attempts to test or "warrant" a scientific theory by means of predicting future observations. A comparison of actual observations, with a suitable definition and range of measurement, will then define a warrant for a scientific theory. In the prescriptive process, on the other hand, one cannot confirm the adequacy of a value or policy by predicting one's own decisions, since these values are the indices which determine these decisions. Such a test would merely demonstrate a degree of consistency with respect to policy. We have gradually become aware that the prescriptive process is somehow different from the predictive process. In subsequent developments of the theory we have found that the differences and similarities between prescription and prediction are fairly complex, as I shall attempt to demonstrate.

Failing to find a rational prototype for the validation of prescriptive processes, we turned to a survey of historical and contemporary ethical and value theories. Although we found literally dozens of philosophical schools which purported to provide a means of selection and control of ethical systems, all of them exhibited inadequacies of various kinds. Failures of these systems and the historical failures of older ethical systems and scientific methods have occurred in a characteristic pattern: ultimately they have been confronted with situations which could not be resolved by the principles espoused.

It may also be observed that, to a large degree, it has been supposed that three great rational methodologies are treated as if they were separate processes. I am referring to (1) axiomatics, a selective system that produces valid formal systems, (2) scientific method, a selective system that produces predictive theories, and (3) axiological method, a method that produces prescriptives, policies, ethics. It has been assumed that axiomatics may be adequately controlled entirely by the rules of logic. On the other hand, the history of the scientific method has been characterized by the accretion of both logical and empirical controls and, in modern science to some degree, by the injection of intuitional controls. The axiologies have been presumed to have been controlled entirely by intuition. There have been, of course, attempts to approach ethics and values from a naturalistic viewpoint as predictive entities, but these studies can be shown to be concerned with value systems as objects, wherein our chief concern has been with value systems as subjects. (That is, what should my policy and my values be in order to determine my decisions?)

Having failed, then, to fine a rational prototype for the warranting of the prescriptive process, we have been forced to attempt a reconstruction in the philosophical foundations of the rational method in order to incorporate axiologies into the group of systematic rational pursuits. This reconstruction has taken the nature of a synthesis among modern scientific methods and contemporary and historic value and ethical theories. It promises, besides its direct application to axiology, to yield additional enlightenment on axiomatics (that is, the control of mathematical method) and the scientific method. This intimation is pertinent to the objectives of this conference and represents the specific subject of my discussion.

THE DEVELOPMENT OF A METATHEORY. It is desirable to distinquish between metatheory and object-theory. An object-theory is a theory which objectifies, or externalizes, objects. Such theories create the following types of objects: the objects of mathematics and logic are sets of self-consistent formal statements together with their consequent theorems; the objects of science are particular predictive theories and the elements thereof; and the objects of axiologies are particular policies that determine or prescribe practical decision. A metatheory, on the other hand, is a theory about object-theories. In particular it is a theory about the methods of admission or control and warrant of object theories. Our theory is a metatheory in which we are attempting to synthesize the metatheories of mathematics, science and axiology under one conformal perspective.

Any such theory presupposes, explicitly or implicitly, certain ontological and epistemological commitments, i.e., commitments as to what constitutes existence and knowledge respectively. Central among our commitments is the notion of relativism in three facets: the first is onotological relativism. This refers to the doctrine that existence of an object-construct is determined by its testability in principle or its connectability by inference to other object-constructs which are testable in principle. In other words, one rejects the notion of things-in-themselves or concepts which, by their very nature, are not subject to test. The term "test," of course, refers not only to empirical tests but to intuitive and formal tests as well.

The second facet is relativism in epistemology. This refers to the doctrine that certainty of knowledge of object-constructs, i.e., the establishment of apodictic truth (truth by necessity) is not obtainable. One must observe that the proofs of validity or warrantability of any scientific theory merely determine the efficiency of that theory in coordinating and clarifying the information obtained under a consistent predictive format. There is never any certainty that some other theory may not be developed which would describe the observations equally well or better; nor is there any certainty that the presently accepted theory will be adequate with respect to any future information that may be obtained. The consequence of these observations is that absoluteness at the object level is not meaningful.

A third facet is perspective relativism. This refers to the doctrine that an absolute reference for the judgment of object-theories is not obtainable. As we shall see in a moment, the consequence of this commitment is Einstein's principle of invariant transformations.

A second commitment presupposed by our meta-theory is that the sole function of the metacognitive process is the assurance of decidability of object-statements--that is, decidability with respect to their admissibility. The concept here is that relativism in object-space leads to degrees of freedom. Decision as to which object-constructs in this range of freedom are to be admitted must be accomplished in terms of some metaprinciple or control. This control then becomes a new absolute replacing the absolutes relinquished at the object level. That is, the controls are categorical, and they are metacontrols. The consequence is the conclusion that <u>ambiguity is the sole motivation for decision</u>.

<u>THEORY OF COGNITIVE CONTROLS</u>. There are, however, many kinds of ambiguities and each type of ambiguity necessitates a corresponding control. As we have said before, these controls

are categorical and their sole function is to resolve ambiguities of the class to which they apply. We have classified the controls in terms of three factors which we call formal, extrospective, and introspective. Besides these reflexive or internal controls there are also sets of external controls which we refer to as evolutionary and aesthetic. One of the great difficulties in developing an acceptable metatheory is collection of provision for selection among alternative object-theories which purport to apply to the same problematic situations. This selection is accomplished by means of evolutionary control--a generalization of the Darwinian principle--and aesthetic control (elegance). The evolutionary controls (fruitfulness, adaptability, and survival) represent ultimate commitments. Since the general thesis of this presentation can be developed without an elaboration of these important concepts, and since time does not permit such an elaboration, we shall forego any further discussion on these topics.

Central to our theory is the concept "objectification." Objectification represents the emergent result of a creative act which externalizes, at the level of a cognitive agent or self, a set of new conceptual entities or object-constructs on a trial basis as an act of policy and subject to a warrant to be established for predictive or prescriptive purposes by a set of cognitive controls. In this viewpoint all rational process is undertaken in terms of object-constructs, a special class of object-constructs being theories or models.

The formal controls of an object-construct apply to its format or formal properties. They insure admissibility under tests of consistence, completeness and independence.

Extrospective Controls. There are two acts in the extrospective control. One is the determination of the criteria of fact--that is, the selection of the specification of what constitutes a relevant fact based on a formal objectification selected among an indefinite set of objectifications as an act of policy. The criteria of fact becomes a filter through which extrospection is admitted as relevant to the problematic situation at hand. Thus, in the act of its admission, any "fact" has formal, introspective and extrospective components. There is no such thing as a purely extrospective fact. This supports the views of contemporary philosophers of science. So let me repeat: this conference, concerned as it is with the design of experiment, or as I have called it, the criteria of fact, is concerned with much more than extrospective information or data. In particular, it is concerned with formal and introspective (that is, intuitive) properties. Now "extrospection" means a looking outwards, or receptivity to

information processed through transducers and subsystems whose outputs are presented to mediation at conscious level. On the basis of the objectification or model one undertakes a prediction, that is, a symbolic projection forward in time beginning with an extrospectively determined initial state and in terms of a specific objectification. This leads to an expectation. A significant discrepancy at a later time between expectation and extrospection engenders extrospective ambiguity. In order to define extrospective ambiguity, one must first select (a) a range of initial admissible expectations, (b) a range of admissible divergencies between expectation and extrospection at a later time, and (c) a frequency measure. We can now define extrospective ambiguity as follows: a set of final expectations and extrospections are empirically nonambiguous if, and only if, a set of histories all beginning with initial states in the admissible range are examined and are found to contain a subset of final states lying in the admissible range around expectation, such that the ratio of the number of final admissible histories to the number of initial admissible histories is equal to or greater than the frequency measure.

The decisions as to the admissible initial and final ranges and the frequency measures are determined by the problematic situations which are desired to be resolved by the objectification. This range of application represents an aesthetic decision. One could, for example (see Table 1), set the frequency measure equal to zero, in which case he is saying he is indifferent to the correspondence between expectation and extrospection. He then becomes, by this aesthetic orientation, primarily concerned with the formal properties of his objectification. That is, he becomes a mathematician. He maintains an interest in the residual substantive properties of his constructs as exhibited by his attention to the nature and efficiency of his notation.

If the range of problematic situations desired to be faced includes prediction of situations, then the frequency measure is set at a non-zero value. We shall call such a person a scientist provided that he has also set his norms with respect to action implied by his objectification at null values, such that he is indifferent to such action. If he becomes aesthetically oriented completely toward action with respect to all immediate and mediate problematic situations, he will, in general, find that he has greater difficulty in satisfying all of the cognitive controls and hence, facing more restrictive constraints, must reduce the scope of comprehensiveness of his models. A primary control is that of practicability. What is practicable with respect to an action problem may be oversimplified with respect to a predictive problem. What is practicable to a scientist may be impractical

Table 1

A UNIFIED META-CONTROL SYSTEM

Metasystem	Operation	Range of problematic situations	Aesthetic Decisions	Scope of objectifications practicable
Axiology	Retrodiction	All practical problems	All norms effective	Most severely restrained, most reduced
Science	Prediction	Specific predictive situations	Action norms at indifference	Restrictions moderate, richer range of objectifications
Axiomatics	Formal extension	Consistent axiomatic systems	Action norms at indifference, extrospective ambiguity measure at null	Least restricted, richest in formal content

to a man of action, etc., the objectifications becoming correspondingly richer as one goes from axiology, to science, to mathematics, as the cognitive controls become, in some sense, degenerate.

There is also a very important difference between the viewpoint of prescription and the viewpoint of prediction--that is, the prescriptive operation, although it may warrant its objectification or model predictively, when it is used in prescription it is turned around and used retrodictively. Now, retrodiction is not the exact reverse of the predictive process. It is this difference between retrodiction and prediction which makes science and axiology acquire complementary characteristics. One is said to be adjoint to the other.

This property has very important philosophical as well as methodological implications. In particular, the primal or predictive viewpoint represents the view of a construct as an object whereas the complementary or dual can be interpreted as a representation of the construct as a subject. Thus, in terms of value theory, predictive value theory is a system by means of which one observes the decisions of another person as data and makes a theory the value system of that person as an object. On the prescriptive side of value theory, one is concerned with one's own values as determinants of one's own decisions. It is this process that is retrodictive.

Introspective Controls. Time will not permit a detailed discussion of introspective controls. We shall endeavor, however, to say enough about these so that their function and importance can be realized. Let us look at perspective control. This is the direct application of our epistomological commitment to perspective relativism. One may refer a statement in an objectification to a particular context of coordinate systems. Ultimately, they may be transformed into another and a description made in terms of another coordinate system. If this transformation depends upon the procedure or path taken from one system to another, one would naturally get a different result from the transformation depending upon the path taken. This would result in what we may call perspective ambiguity. If there existed an absolute point of reference, then a natural algorithm for transformations would be indicated. One would simply transform from the first coordinate system to the absolute origin and from there to the new coordinate system. In the absence of any such absolute perspective, one must limit the transformations to those having a particular property.

We seek a class of transformations which do not lead to ambiguity, regardless of the procedure or path taken. These are

called invariant transformations and they result in a formal description in the new coordinate system which is identical to the formal description in the old coordinate system. This is the principle of invariance. While it has a rather abstract title, and while the discovery of invariant transformations may sometimes be difficult, the intent and meaning of the principle is very simple. It says merely that one must avoid procedurally induced ambiguities.

In a space-time transformation of a physical theory, this leads directly to the Lorentz-Einstein conditions for a space-time transformation. Now it is also true and also of interest that if one looks at an object-space determined by a Markov stochastic system and asks for a nonambiguous or invariant transformation of a velocity in a Markov space (i.e., the velocity of movement of a probability configuration), half of the conditions for an invariant transformation emerge as a result. The adoption of the second half, as necessary for an invariant transformation, is equivalent to the introduction of the set of imaginary probabilities which, together with the real Markov probabilities, are to be associated with each transition. The results*, which may not surprise you by now, are none other than, again, the Lorentz-Einstein transformation equations in the space defined by the Markovian system.

Before the time of Einstein, science and axiology were presumed to be entirely separate, science being the province of empiricism and formal logic, whereas axiology, separate and disconnected, was the province of intuition. Then Einstein shook the very foundations of physical theory by a brillant and successful modification of the cherished concepts of space and time--a modification which depended not on empirical discovery but upon application of an intuitional requirement.

Even today the commitment to empiricism is sufficiently strong, and naive realism is so firmly established, that the full significance of Einstein's principle is not realized. This principle does not refer to a singular discovery of a property of the external world, but instead to a necessary property of admissible forms which may serve as objectifications for applicable symbolizations. We are constrained to think in terms of perspectively invariant forms, or we are inevitably led to ambiguity. Einstein, having achieved a nonambiguous formulation of mechanics, was then able to proceed to show a relation between energy and mass. The relation between energy and mass is not a substantive consequence of relativistic invariance; it is merely a formal result educed by an enlightened procedure which was made possible by a form of nonambiguous thinking.

*Smith, Nicholas M., "A Calculus for Ethics: A Theory of the Structure of Value," Behavioral Science, Vol. 1, Nos. 2, 3. 1956.

Other Implications of Invariance. Einstein's invariance has other far-reaching implications, particularly when we generalize the principle to state that all formal objectifications must be invariance with respect to significant transformations. "Significant" transformations are those in which the ambiguity arising from noninvariancy will be distinguishable from the range of admissible extrospective error. Generalized invariance has particular importance and implication in value-decision theory. One demands by application of this principle that the transformation of decision from a present to a future state by means of the Chapman-Kolmogorov transformation shall lead to a form of the value-decision equation identical with the initial one. If this were not true, then the decision indicated by the value-decision equation would depend upon the procedure in which a decision was staged into parts for analysis. The requirement of invariance with respect to time-translation transformation is insured first by the nature of the Chapman-Kolmogorov equation, and second by the placing of an important restriction on the decision operator. This restriction is one of commutation. A decision operator which commutes through the stages of decision process will permit an invariant transformation of the equation as applied from one point of reference in time to another. This property is also known by another name. It is the principle of optimality of dynamic programming. The latter is connectable to Euler's Weirstrasse and Legendre conditions of steepest descent algorithms.

It may also be shown that the Chapman-Kolmogorov equation, as it enters into value theory, introduces a concept analogous to momentum by virtue of the fact that the value equation is analogous to the conservation of momentum. Again the selection of a model in which the Chapman-Kolmogorov equation applies has been based upon the need for an invariant model as a starting point for the building of a theory. It also may lead, one adds, to a suggested generalization or modification of the law of conservation of momentum.

Other Introspective Controls. There are other introspective controls, each in its way fully as important as the principle of invariance; and each, when stripped of technical verbiage, merely assures nonambiguity and therefore decidability in the object-model.

One of these controls refers to the context of an object-construct. It requires that the context be specified in order to complete the meaning of the construct and it further specifies that an object-construct may have only one context, since if it had more than one context, it would be ambiguous. This particular

control, a modification of the Russell-Whitehead theory of types, can be expected to have important significance in the removal of certain kinds of paradoxes from modern logic.

Another introspective control, which is a direct statement of onotological relativity, constrains all object-constructs to those which are testable in principle. A third control requires furthermore that the test of the construct must not only be attainable in principle, it must be attainable and interpretable in terms of finite processes. This control will rule out infinite processes and continuous time-space as directly applicable to substantive constructs. Such concepts must assume a secondary status--that of operating constructs which guide the interpretation of finite extrospection in the context of a particular objectification. Examples of such secondary or operating constructs are: the wave functions of wave mechanics (which operate away in the act of evaluating a measurable entity), the concept "true" probability, which is never attainable; the optimum in a decision process, which is never achievable; also included is the class of decision variables as contrasted with the class of object variables.

The effect of introspective controls is to restrain the selection of object-models which are admissible for serving as the formal content of object-constructs. It therefore should come as no surprise that the form of all successful theories (that is, theories which prove to be admissible under extrospective, introspective and formal tests) will shown strong analogies.

Nor is it surprising that scientists have discovered introspective principles in the course of empirical investigations and have believed them to be part of the extrospective content of their observations.

This is not to say that these explicit principles, when they appear, are wholly intuitive, but rather that they are the consequents of intuitive requirements. A successful theory--no matter in what terminology it is formulated--will contain these principles in order to be nonambiguous.

Modern mathematicians have rediscovered Einstein's principle of invariance recently and have given it a name implying an extrospective connotation--they call it the principle of causality, and further, go so far as to say that it is the basic principle of classical physics.

These sets of controls alone are not sufficient to determine decidability. They are reflexive controls only. Ultimate decidability depends also on evolutionary controls, aesthetic controls, and on an intuitively established and evolutionary validated set of norms. Time does not permit discussion of them here. Their introduction and application merely serve to support the statement that extrospection is only a part of a concept, indeed, that the criterion of fact, although a necessary and desirable part of the rational process, must be imbedded for its understanding in the context of the metasystem. The nature of the evolutionary control is to insure fruitfulness, adaptability and survival of a concept as a workable construct. Formalizations which have inherent ambiguities must necessarily sooner or later reach a condition where decidability cannot be established; and they must surely fail. This does not imply that once a method of rational inquiry is devised which accomplishes decidability it can be expected to retain this property indefinitely.

Novelty is a characteristic of emerging concepts. Novelty will inevitably occur in the method of inquiry itself. The appearance of higher orders of abstraction will make necessary a re-establishment of cognitive control evolving through a repetitive cycle of ambiguity, undecidability, and finally the discovery of new rational principles.

CONCLUSION. The conclusion I wish to draw from these remarks is that knowledge depends as much upon intuition as it does upon extrospection and logic; and that these aspects are interdependent. I have hoped to make you aware of the implication that the nature of the rational act is much more complicated than heretofore supposed and that the simplistic views of cognition must irrevocably be discarded.