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Pragmatism, mathematical models, and the scientific ideal of prediction and control

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ABSTRACT

Mathematical models are often held to be valuable, if not necessary, for theories and explanations in the quantitative analysis of behavior. The present review suggests that mathematical models primarily derived from the observation of functional relations do indeed contribute to the scientific value of theories and explanations, even though the final form of the models appears to be highly abstract. However, mathematical models not primarily so derived risk being essentialist in character, based on a particular view of formal causation. Such models invite less effective and frequently mentalistic theories and explanations of behavior. Models may be evaluated in terms of both (a) the verbal processes responsible for their origin and development and (b) the prediction and control engendered by the theories and explanations that incorporate the models, however indirect or abstract that prediction and control may be. Overall, the present review suggests that technological application and theoretical contemplation may be usefully viewed as continuous and overlapping forms of scientific activity, rather than dichotomous and mutually exclusive.

1. Pragmatism, models, and the ideal of prediction and control

It is often argued that science is concerned not only with prediction and control but with understanding or even with simple contemplation, but scientific knowledge is not an elaborated perception of the external world in the mind of the scientist but rather what scientists do about the world (Skinner, 1969).

A longstanding concern in the scientific study of behavior as a subject matter is the degree to which behavior can be predicted and controlled. This concern is well over 100 years old, and is represented in words that are no doubt familiar to many: "All natural sciences aim at practical prediction and control and in none of them is this more the case than psychology to-day," (James, 1892); and "psychology as the behaviorist views it is a purely objective experimental branch of natural science. Its theoretical goal is the prediction and control of behavior" (Watson, 1913).

The quantitative analysis of behavior is concerned with the application of quantitative techniques to the study of the contingent relations between environmental circumstances as an independent variable and an organism's responding as a dependent variable. The goal is to better understand the relations that control behavior in all its complexity. Given a better understanding of these relations, behavior can be better predicted and controlled in the laboratory, in the clinic, in the classroom, or in the world at large, for nonhumans and humans alike.

Many associate the quantitative analysis of behavior with the research tradition begun in the Harvard Pigeon Laboratory in the 1960s by Richard Herrnstein and his students, and carried on by many others in the subsequent years, both in the Harvard department and elsewhere. Clearly, much important work did begin in this decade. Nevertheless, it is important to recognize that when B.F. Skinner was a graduate student and post-doctoral fellow in the late 1920s and early 1930s, he was intimately interested in securing a quantitative account of behavior. Skinner described his interest as follows: "I never faced a Problem which was more than the eternal problem of finding order... Of course, I was working on a basic Assumption—that there was order in behavior if I could only discover it" (Skinner, 1972).

The order that Skinner sought when he was a graduate student was quantitative order. Skinner pursued a diverse research agenda when he was a graduate student. His favored subjects were rats.

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In one set of projects, he investigated locomotor responses, such as running in a straight alley and in a running wheel. Unfortunately, he found no particular quantitative order with these preparations. In another, he investigated the "ingestion reflex." The ingestion reflex, of course, was an alternative name for eating. More specifically, in his dissertation research he developed an experimental chamber in which the rat would receive a single pellet each time it pushed open a door panel (Moore, 2005; Skinner, 1972). Skinner then recorded the number of food pellets a rat ate per unit of time during a two hour observation period. Perhaps not surprisingly, he found that the rat ate many pellets at first but then fewer and fewer as time passed. He proudly described his research in a letter to his parents in March, 1930:

Letter to parents, March, 1930: "The greatest birthday present I got was some remarkable results from the data of my experiment. Crozier is quite worked up about it. It is a complicated business and deep in mathematics. In a word, I have demonstrated that the rate at which a rat eats food, over a period of two hours, is a square function of the time. In other words, what heretofore was supposed to be "free" behavior on the part of a rat is now shown to be just as much subject to natural laws as, for example, the rate of his pulse." (Skinner, 1979)

The "square function" to which Skinner refers is a plot of the square of the number of pellets eaten against time: $N^2 = kT$, where N is the number of pellets eaten, T is time, and k is an individual difference parameter.

However, as Skinner's research progressed, the square function didn't prove as general as he first thought. He then tried other ways of plotting the data. When he plotted the logarithm of the number of pellets eaten against the logarithm of time, he did find order. The data were well described by a power law, $N = kT^a$, where the value of the exponent a was about 0.7. Fig. 1 shows Skinner's data, taken from Coleman (1987, p. 59). Somewhat later, while a postdoctoral fellow, Skinner modified his preparation by replacing the door panel with a lever made of bent wire. When the rat pressed the lever, the rat produced a single pellet. The power law function with lever pressing was consistent with that of door pushing, confirming a quantitative orderliness at the level of a general process in two laboratory preparations, pushing open a door panel and pressing down a lever.

As was Skinner, many contemporary psychologists are interested in how mathematical models contribute to theories and explanations in the quantitative analysis of behavior. Presumably, the goal of such quantitatively oriented theories and explanations is to promote prediction and control. The term "explanation" may be interpreted in many ways, such as "accounting for", or in a very broad sense "understanding". The present review begins with an examination of one view of science and the role of mathematical models in achieving its goal.

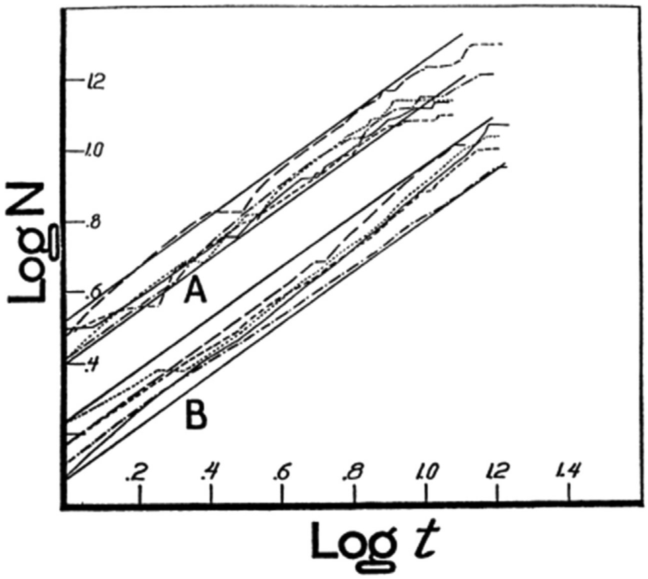

Fig. 1. Data from Skinner's early research.

2. One view of science and the contribution of mathematical models

Moore (2010b) characterized one view of science in the following way. Theories are the ultimate objective of science. A theory is often defined as a symbolic, prototypical representation of (a) observed relations among events, (b) observed mechanisms and structures underlying observed relations, and (c) inferred mechanisms and structures postulated to account for relations for which observed mechanisms and structures cannot account. Theories are necessary in science because they can't be avoided in practice and are uniquely appropriate to processes by which humans acquire knowledge. The standard criteria for evaluating theories are (a) testability/falsifiability, (b) validity, (c) utility, (d) parsimony, and (e) heuristic value. Theories have three types of terms: (a) logical terms, (b) observational terms, and (c) theoretical terms. Logical terms provide the syntax of a theory through its logical operators: negation, conjunction, disjunction, implication, and the like. Observational terms refer to objects or properties of objects than can be publicly observed and measured using the instruments of physics. Theoretical terms refer to unobservables, but must be linked to observables through operational definitions, which specify the procedures entailed in their measurement. Theoretical terms come in two sub-types: (a) intervening variables and (b) hypothetical constructs (MacCorquodale and Meehl, 1948). An intervening variable is a summary term that does not refer to an entity or process that actually exists. Thus, it has no implications or applications beyond its current usage. In the words of MacCorquodale and Meehl, it does not have "surplus meaning". Consequently, the operational definition of an intervening variable is "exhaustive". In contrast, a hypothetical construct does imply an entity or process that does actually exist. Thus, it does have implications and applications beyond its current usage. In the words or MacCorquodale and Meehl, it does have surplus meaning. Consequently, the operational definition of a hypothetical construct is only "partial," in the sense that other meanings, usages, or applications are possible in other settings.

According to this view, psychology should formulate theories having unobservable theoretical terms. The preferred form of theoretical term is a hypothetical construct. Hypothetical constructs mediate causality as "organismic" variables (represented by O) in an S–O–R model. Hypothetical constructs yield greater heuristic value and confer more degrees of freedom in theory development by virtue of their surplus meaning. Finally, they lead to simplified, more parsimonious statements of orderly relations: Theorists need talk of only $m + n$ relations between independent (m) and dependent (n) variables instead of $m \times n$ relations.

What if theories or explanations fail to correctly describe or predict data? One course of action is to uphold the theory and note the contrary case. A second is to simply state the limitations and boundaries. A third is to add auxiliary assumptions. A fourth is to formulate a new and improved theory or explanation.

Discussions of theories commonly distinguish between the context of discovery and the context of justification. The context of discovery is concerned with determining the source of a knowledge claim. The context of discovery is not ordinarily regarded as a matter of science, but rather of history or sociology. The context of