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Comment

George Box

Reading this stimulating paper, I was particularly intrigued by the section on Theory, Application and Education. As Harry Roberts points out, experience with the modern quality movement highlights many important issues. It underlines the necessity for a much wider definition for theoretical statistics. It makes explicit the necessarily iterative nature of investigation as exemplified by the Shewhart Cycle, by the goal of *never-ending* improvement and by the complementary roles of Tukey's exploratory and confirmatory data analysis. It demonstrates how simple graphical techniques, such as Ishikawa's Seven Tools, although ludicrously simple mathematically, can be enormously powerful scientifically because they are devoted to the inductive step of hypothesis *generation* that mathematical statistics so often ignores.

Most subjects have a theoretical as well as an applied side, and ideally each nourishes the other; but for statistics I believe this has not always been true. In my view, statistics has no reason for existence except as the catalyst for investigation and discovery. If this is true then, above all else, the proper study of the statistician is scientific method and therefore statistics should serve the needs of that study. An understanding of the process of investigation involves such things as the roles of induction as well as deduction, the nature of scientific learning, the importance of subject matter knowledge, the psychology of investigators and the management of data acquisition and experiment. The *theory* of statistics should be concerned with all these things.

Unfortunately, its domination by mathematics has led to the teaching and propagation of ideas that I believe are in some cases actually antithetical to good statistical practice. Consider the process of investigation itself as exemplified, for example, by any good detective novel, by any reasonably honest account of scientific research (such as Watson's account of the discovery of the double helix) or by the process of finding out why a manufacturing system is producing low quality product. This process of investigation employs induction and deduction in an iterative

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sequence, which is full of arbitrary judgment. Sherlock Holmes must decide whether his time will best be spent questioning the one-eyed ticket collector at Baker Street Station or looking for the tell-tale footprint under Lady Cynthia's window. Similarly the investigator of the poor quality process who decides to run a designed experiment must answer questions such as: Which variables should we study? Over what ranges should we vary them? In what metric should we consider them? What type and how complicated a model should we use? What sort of experimental design should be employed? The (arbitrary) answers must be arrived at by good judgment and this determines success or failure much more than the calculation, for example, of an "exact" confidence interval, and again underlines the necessity for the iterative approach.

Judgmental questions of this kind arise in every application of statistics. But, our budding statisticians and future teachers of statistics—graduate students, post docs and junior faculty—can, I believe, only learn good judgment in the same way as does the medical profession. They must in effect serve an internship in which they are involved with real ongoing investigation and gain the experience of working with real investigators. The present policy of university departments and granting agencies produces exactly the opposite result. Only doctoral theses concerned with mathematical theory and single authored mathematical papers bring acceptance and eventual tenure. Joint investigations with subject matter specialists and the resulting publications, which should be mandatory, are in fact discounted and discouraged.

I once likened this process to teaching swimming by lecturing the students on the theory of buoyancy and the advantages and disadvantages of various strokes with the expectation that at the end of three or four years of such training they could all jump in the pool and swim. But it is actually worse than that. While many of the students taking Masters degrees are eventually allowed to get in the pool and those that do not first drown can perhaps teach themselves to swim, our greatest ambition for our Ph.D. students is that they never get wet. Instead we hope they will become professors and teach the next batch of students what they have learned.

Comment

W. Edwards Deming

This paper by Dr. Roberts is meritorious, in my opinion. I hope that many statisticians will read it, though nonstatisticians need it even more.

Dr. Roberts, as I understand it, takes the point of view that the aim of statistical reasoning in business should be pursuit of company goals. There is another point of view. In my own work and teaching, the business of statisticians is to transform the company goals—not to help the management to pursue theirs, but to change those goals. It is company goals that for three decades have put this country on the decline. Nothing short of transformation of company goals will halt this continual decline.

The aim of business should be optimization of the whole system of production and service. The statistician can contribute to optimization more than anyone. A system consists of four parts: appreciation for a system, some knowledge of the theory of variation, theory of knowledge and psychology.

A system must be managed. The aim of the system must be stated by the management thereof. Without an aim, there is no system. The components of a system are necessary but not sufficient of themselves to accomplish the aim. They must be managed.

I propose that the aim for management should be for everybody to gain—stockholders, employees, suppliers, customers, community, the environment—over the long term.

If psychologists understood variation, they could no longer participate in continual refinements of instruments for rating people.

If statisticians understood a system, and they understood some theory of knowledge and something about psychology, they could no longer teach tests of significance, tests of hypothesis and chi-square. Statistical theory is helpful for understanding differences between people, interactions between people, and interactions between people and the system that they work in, or learn in.

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