OLDFORD, R.W. (1995) "A PHYSICAL DEVICE FOR DEMONSTRATING CONFOUNDING, BLOCKING, AND THE ROLE OF RANDOMIZATION IN UNCOVERING A CAUSAL RELATIONSHIP," *THE AMERICAN STATISTICIAN*, 49, 210-216: COMMENT BY JUDEA PEARL

Oldford (1995) presents an ingenious teaching device which vividly displays the difficulties associated with attributing causal interpretation to regression equations, and thus enhances students' appreciation for several aspects of causal relations and experimental design. This letter proposes a more drastic reform of current teaching of causality, one based on replacing the vocabulary of regression analysis with extensive use of causal diagrams.

Oldford advocates, and I agree, that in the classroom the teacher should define the parameter β of the causal equation

$$Y = \alpha + \beta X + \gamma Z \tag{1}$$

as "the change expected in y when x is changed by a unit amount and everything else (i.e., z) is held fixed." However, the routine translation of "is changed" and "is held fixed" into the language of conditional expectations – as in "...they [students] need to fix z and examine the relationship between x and y conditioned on z" – may lead to disaster. To illustrate: Consider an extreme case where z and x are functionally related, say through $z = ax + b$, (e.g., the amount of blood transfused (z) was determined as a (linear) function of the amount (x) of anesthetic used). This would render y and x conditionally independent given z and would bias regressional calculations of β to zero (or, at best, leave β undetermined) regardless of the actual value of β in Eq. 1. Such bias is not limited to functional relationships between x and z; in the general case, where a disturbance term ϵ (uncorrelated with x) is introduced into Eq. 1, the bias surfaces when z is correlated with both x and ϵ. Thus, teachers should discourage the routine translation of causal notions (e.g.,"fix z") into regressional notions (e.g., "conditioned on z").

The confusion between regression and causal analysis has long been a focus of discontention between statisticians, on the one hand, and econometricians and social scientists, on the other (Freedman, 1987 and Wermuth, 1992). The source of this controversy is indeed the expression "holding z fixed," which economists and social scientists interpret as "fixing z by external intervention," and statisticians interpret as "conditioning on z," namely, considering only samples in which z attains a certain value. While the distinction between "fixing" and "conditioning" cannot be formulated in the standard language of statistical analysis, it is vividly displayed in the language of causal diagrams (Spirtes etal., 1993; Pearl, 1993), a language that clarifies and explicates the precise conditions under which the two interpretations are interchangeable (Pearl, 1995).

Thus, the most basic problem of causal analysis, namely, whether adding a variate z to a regression equation will or will not bias the result, is left unanswered in Oldford's approach, as it is in all statistics textbooks. Past neglect of this problem can partially be attributed to mathematical deficiency: the assumptions needed for such determination rest on causal considerations, and statistics lacks the mathematical machinery for encoding causal assumptions formally. However, advances in graphical models now permit precise mathematical formulation of such assumptions and have yielded a simple graphical solution to the problem above (Pearl, 1995) and to many of its ramifications (Pearl and Robbins, 1995). These developments, coupled with the natural appeal of graphs in causal modeling, make causal diagrams an indispensable tool in the teaching of causality to undergraduate statistics students.

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