In Memoriam

George E. P. Box

(1919–2013)

GEORGE E. P. BOX, one of the world's leading statisticians for more than 60 years, died on March 28, 2013, at his home in Madison WI.

George Box was born and raised in Gravesend, England. Initially trained as a chemist, he was fond of relating how his career in statistics began during World War II, when he served as a lab assistant with a unit working to develop and test antidotes that could be used if England were attacked with poison gas. He realized that the team needed a statistician who could help them better understand their test data and, upon presenting that need to his commanding officer, found himself appointed to the position. He proceeded to design and analyze hundreds of experiments and even to meet with R. A. Fisher on one particularly challenging problem. His recently released memoir provides details on his experiences in the war and later in life (Box 2013).

After the war, George Box joined Imperial Chemical Industries (ICI) as a staff scientist working to improve industrial processes. He also enrolled at London University and in 1952 completed his Ph. D. in statistics under the supervision of H. O. Hartley. He came to the United States in 1953 as a guest scholar at North Carolina State University, at the institute headed by Gertrude Cox. Stu Hunter, then a student at NC State, helped to arrange the visit and generous funding was provided by Frank Grubbs from the Army Research Office. After three more years at ICI, Box returned to the US at the invitation of John Tukey to direct the Statistical Techniques Research Group at Princeton University. The STRG was an extremely productive team, whose members included, among others, Stu Hunter, Don Behnken, Collin Mallows, Geoff Watson, Henry Sheffé, Merve Muller, Norman Draper, and Gwilym Jenkins. In 1959 he left Princeton to found the Department of Statistics at the University of Wisconsin, which became one of the leading departments in the United States. He was later recognized with a Vilas Professorship, the highest honor granted by UW. In 1985 Box joined Bill Hunter in founding UW's Center for Quality and Productivity Improvement (CQPI), which achieved international renown for conducting and disseminating research on quality.

George Box leaves a remarkable intellectual legacy. He wrote eight books and was a collaborator on two more; he published more than 200 articles. His ideas had a major influence on many statisticians and the insightful and efficient statistical methods that he pioneered have achieved widespread use in diverse scientific fields. Many scientists and engineers learned about the benefits of designed experiments from his classic text, *Statistics for Experimenters*, written with Bill Hunter and Stu Hunter. "Box and Jenkins" became synonymous with their paradigm for analyzing time series data and "Box and Cox" with the effective use of data transformations.

In 1951 Box published a path-breaking paper on response surface methods (RSM) together with K. B. Wilson, a colleague of his at ICI. The stimulus for developing RSM was to find efficient experimental methods for improving the yield of chemical processes. Box and his colleagues developed new classes of designs, like the central composite, new concepts for designs, like resolution and rotatability, and the theory of sequential experimentation and exploration. And in parallel, they achieved many breakthroughs in yield improvement. Practical problems drove theoretical research which in turn was used to attack new problems, a discourse between application and theory that would resonate throughout Box's professional career.

Another area where George Box made major contributions was time series analysis, culminating in his book with Gwilym Jenkins, and subsequently revised together with Greg Reinsel. That research, as well, had its roots in an applied problem—developing methods for feedback control of the output of a continuous process. One of the key features of this work was the iterative modeling strategy employed by the authors. The process began with informative statistics and graphs for identifying models, proceeded to

methods for estimating an assumed model, and then to diagnostic methods using residuals to criticize the model. Often the statistical analysis involved several cycles of identification, estimation and criticism.

In the 1960's Box became a strong proponent of Bayesian inference. Together with George Tiao he studied questions such as the choice of prior distributions, random effects models and inference for variance components, estimating common regression coefficients, data transformation and the role of assumptions. An interesting paper in 1983 argued that Bayesian inference was the approach best suited to estimation whereas sampling theory (via comparison to the predictive distribution) was needed for model criticism.

George Box returned to quality and to designed experiments in the early 1980's spurred by the quality engineering ideas of Genichi Taguchi and the revival of interest in quality in the US. Designed experiments were one of the key tools in quality engineering. Box, along with several students, critically examined the use of experiments for quality improvement, exploring the importance of assumptions and deriving alternative methods that were often superior and/or more general. An important aspect of Box's work was to frame the methods by placing them in a broader scientific quality context (Box and Bisgaard 1987).

CQPI was attracting many visitors at this time. One of them, Alberto Luceño, proved to be an ideal collaborator. Box and Luceño set out to study the links between statistical process control and the feedback and feed-forward control strategies used by engineers. The two approaches appeared, on the surface, contradictory: SPC advocated tracking processes and intervening only when there was a clear signal of an assignable cause, whereas engineering control made regular adjustments to process parameters. Box and Luceño showed how these approaches could complement and improve one another in a series of articles and then in their book *Statistical Control by Monitoring and Feedback Adjustment*. A fundamental tenet of the work, and one that would guide Box's subsequent writing on process control, is that processes, left to their own, will rarely if ever be stationary; rather, they will drift away from any target value (Box and Luceño 2000).

In my view, George Box's most important scientific contribution was in his unique vision of how statistics connects with scientific inquiry and how that context is (or at least should be) critical in shaping statistics and statistical research. His research in experimental design is an ideal illustration. The first major contributions grew out of first-hand collaboration at ICI with scientists who needed to study processes. He began by observing how these scientists ran experiments. Their work was characterized by the immediacy of the results (which were typically available within days, and sometimes within minutes) and sequential progress, with the results of each set of runs affecting subsequent planning. That might entail dropping some factors or adding new ones, changing the range of factors, or adding new intermediate levels of a factor. These features of the experimental context differed in important ways from the agricultural experiments that had motivated Fisher. Response surface methods (Box and Wilson 1951) arose from Box's interaction with that experimental context. The fundamental statistical insight of RSM was the strategy of running sequential experiments, with rapid feedback. A rich body of technical research followed, exploiting the fact that low order polynomials would often be useful empirical models and that designs for fitting those models could be much more economical than fractional factorials with factors at many levels. For more detail, see Box (1984, 1999).

Box's (1976) diagram of scientific iteration, going from induction (model criticism and hypothesis forming) to deduction (estimation), with informative data collected at each step, is a guideline for using statistics to learn. He wrote critically of the tendency for statistical theory to focus on single steps in that process as though science was a one-shot experiment.

In his academic work, Box also stressed the importance of practice in statistics. Concerned that the graduate students were not sufficiently involved in applied science, he established the Monday Night Beer and Statistics Symposium, which became one of the great traditions in the department. Each week a guest speaker would present a research problem with some challenging statistical issues, followed by a wide ranging discussion over beer and cider. Box was a true master in these sessions: he had a great sense for cutting to the heart of problems, identifying hidden assumptions and probing weaknesses in the design or data that could be improved via further data collection. It was a marvelous arena to see statistics in action and a great learning experience.

Few statisticians have written so clearly and effectively as George Box. Perhaps the single most

memorable phrase is his comment that "all models are wrong, but some are useful". He also introduced the term "robustness" to the statistical vocabulary. His communication skills are especially evident in the regular feature "George's Column" published in Quality Engineering from 1989 until 1993 (later "Quality Quandaries", written jointly with Søren Bisgaard). These are wonderfully sculpted short columns with great practical advice and valuable insights on using statistical ideas in the pursuit of quality and process improvement. One of my favorites, "How to Get Lucky", argues that someone who is *consistently lucky* is no doubt creating circumstances that foster learning and understanding (Box 1993). This idea stimulates a discussion of how to be *consistently lucky* and describes the benefits that will result for quality improvement programs.

George Box received numerous awards and honors, including the Deming and Shewhart Medals. The recognition he most cherished was becoming a Fellow of the Royal Society of England, an honor granted to only a small number of highly influential scientists. He was a leader in the profession, serving as president of both the American Statistical Association and the Institute for Mathematical Statistics.

George Box was a delightful companion and a good friend. He had a keen sense of humor, loved a good story and was a superb story-teller. He left us with an enduring legacy. I am grateful that I had the privilege of joining him for parts of that journey.

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