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George Box, quality, and improving almost anything

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The quality movement of the 1980s and 1990s was as if custom-made for George Box. The notion of improvement is statistical at its heart, and the quality imperative brought new energy to a confluence of fields pioneered by him, including industrial experimental design, time series analysis, and robustness.[‡] With a focus on quality since the mid-1980s, Box authored over 100 additional publications of unfailing inventiveness, including a Brumbaugh Award winner when he was 90. He delighted in how the simplest statistical tools of the quality movement democratized the scientific method and shared his insights in popular forums with wit and grace. In this brief reflection, we offer a snapshot of that very rich era.

Keywords: Box; quality improvement; control; robust design; scientific method; Wisconsin

1. You can improve almost anything

George Box loved to tell of the imaginary evolution of a species of lobster as a metaphor for improvement [1]. In the spirit of natural selection whereby successive generations of lobsters improve their chances of survival in possibly changing environments, quality improvement requires just two things: first, that variations exist that can be compared and second, that there will be willful selection of a preferred variation. So one can improve almost anything, Box often said, even one's enjoyment of dining at a restaurant—if only one is willing to try something new half the time. Indeed, purposeful improvement is statistical at its heart. Differences present opportunities, and much of Box's work involved finding differences efficiently—including the act of *creating* informative differences via designed experiments (see the articles by Steinberg, Jones, and Meyer in this issue of *ASMBI*).

One could justifiably say that *all* of Box's work was for the improvement of quality, but in this article, we will concentrate on his work that coincided with the 'quality movement' that began in the early 1980s.

2. Taguchi methods and the first quality and productivity research conference

The inaugural conference on 'Frontiers of Industrial Experimentation'[§] organized by AT&T Bell Laboratories[¶] was held at Mohonk Mountain House in New Paltz, New York on May 23-24, 1984. Its goal was to understand differences between Japanese and US approaches to product and process improvement; in particular, methods associated with Dr. Genichi Taguchi for systematic quality engineering. The key objectives of Taguchi's approach to experimentation and analysis included reduction of product development time, rapid scale-up from pilot plant to manufacturing scale, and the design of products and processes that are 'robust' to variation in their environments or in their components (see the article by Jones in this issue of *ASMBI*).

The first day of the conference was witnessed by the United Press International reporter Steve Geimann[‖]:

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[‡]See the articles by Steinberg; Hill; Abraham, Ledolter, and Ljung; Woodall and del Castillo; Jones; and Meyer in this issue of ASMBI.

[§]The conference was renamed the 'Quality and Productivity Research Conference' (QPRC) in 1985, and continues under that name to this day.

[¶]The key organizers were A. Blanton Godfrey and his staff in the Quality Theory and Technology Department in the Quality Assurance Center at AT&T Bell Labs in Holmdel, NJ.

[‖]Geimann's article appeared with the headline 'Japanese quality control ideas coolly met' in The Jersey Journal, June 5, 1984. The same article appeared with the headline 'U.S. engineers, statisticians scrutinize Japanese techniques' in the Albany Knickerbocker News, June 6, 1984.

> Several participants said the all-day discussion merely scratched the surface of what promises to be a long debate as engineers and statisticians slowly move toward a marriage Japanese industry consummated two decades ago. It is that marriage—of statistical skill and engineering know-how—which has helped Japan produce better products at lower cost, creating immense competition for the United States . . .

Box was not convinced that full credit was due to Taguchi's methods themselves, however, but rather that experimental design concepts were being used at all. As noted by Geimann: ' "The one difference is they're doing it and we're not," said George Box, professor of statistics and engineering at the University of Wisconsin at Madison.'

Box was stimulated to look more deeply into the underpinnings of Taguchi methods. In the Fall semester of 1984, he led a seminar course in the Department of Statistics at the University of Wisconsin in which students took turns studying and presenting chapters of *Introduction to Off-line Quality Control* by Taguchi and Wu [2]. Box continued his research and spoke passionately about his concerns at many conferences over the next 6 years. His fundamental wish was that good ideas be recognized, promoted, and improved upon (especially Taguchi's concept of 'parameter design' for designing products robust[**] to component variation and environmental change); whereas faulty ideas should be identified and discouraged (in particular accumulation analysis, ad hoc signal-to-noise ratios, and improper use of analysis of variance and 'minute' analysis) [3, 4]. Box and a large contingent of students[††] from the University of Wisconsin returned to the Quality and Productivity Research Conference in 1985, at which Taguchi methods were again a key focus, and the first day's afternoon presentations were dedicated to the Wisconsin group's learnings since the prior meeting.

Geimann was prescient in characterizing discussions of Taguchi methods as 'a long debate'. Proponents of Taguchi methods in US companies were unhappy to be challenged by statisticians [5], and Box was dismayed to be called disruptive and counterproductive. From a personal letter received by Box in October of 1988 (author to remain in confidence):

> George, the course for U.S. industrial improvement is now well underway. Rather than incite the ships *(sic)* crew, your efforts would be better spent on the bridge helping to navigate. We need creative leadership to help U.S. industry, and you could contribute a great deal. We don't need statisticians running around the country debating ideas and theory . . . debate among specialists tends to confuse management and in some cases, paralyzes the system. Industry should be encouraged to apply methods that work and not be bogged down by theoretical debates.

Box replied in detail to this correspondent, with the key message that

> Taguchi methods 'work' because experimental design, even if applied inefficiently, is an extremely powerful technique. But if we only follow we will always be behind. If we are to do *better* than our Japanese competitors, we ought not tie ourselves to any particular subset of procedures. Investigations should be problem-driven, not method-driven.

It was precisely this concern that engineering problem-solving must not be forced to depend only on narrowly prescribed methods that had led Box and Søren Bisgaard, with some urgency, to write 'The Scientific Context of Quality Improvement' [6], in which they stressed that modern quality improvement may employ 'techniques ranging from the very simple to the more sophisticated in a never-ending effort to learn more about the product and the process', but that 'Its driving force is scientific method, disseminated throughout the company.' This article received the Brumbaugh Award from the American Society for Quality for the paper that made the largest single contribution to development of industrial application of quality control in 1987.

Stimulated by that era's intense industrial and academic interest in Taguchi methods, Box and colleagues[‡‡] produced many publications to explore, understand, and improve upon those methods, including (i) Box [7], Box, Bisgaard, and Fung [8], and Nair [4] on Taguchi methods overall; (ii) Box and Jones [9, 10], Wendelberger and Box [11], and Box and Fung [12] on robust design; (iii) Box and Fung [13] and Box [3] on signal-to-noise ratios and performance measures; (iv) Box and Jones [14, 15] on accumulation analysis; and (v) Box and Fung [16] on data transformation in designed experiments for life testing. Box's focus on Taguchi methods was largely complete by 1992.

3. Meanwhile . . . the quality era in the city of Madison, Wisconsin

The June, 1980 NBC News program 'If Japan Can . . . Why Can't We?' was life changing for William G. (Bill) Hunter and Brian Joiner, both faculty members in the Department of Statistics at the University of Wisconsin-Madison. Both rededicated their lives to quality; Hunter to focus on doing something for Madison, and Joiner to found a quality improvement

[**] *See the article by Jones in this issue of ASMBI.*

[††] *Søren Bisgaard, Dan Meyer, Conrad Fung, Stephen Jones, Tim Kramer, and Mike Hamada.*

[‡‡] *During this period, Box and colleagues in Wisconsin were supported by the National Science Foundation through an Industry/University Cooperative Research Project Grant jointly with AT&T Bell Labs. Under this grant, the University of Wisconsin and AT&T Bell Labs together sponsored many workshops; and Box and C.F. Jeff Wu from Wisconsin, and Raghu Kackar, Vijay Nair, Madhav Phadke, and Anne Shoemaker from AT&T traveled to Japan to observe quality practices firsthand* [17].

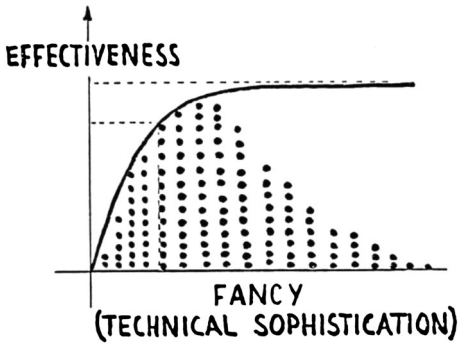

Figure 1. An overhead transparency used by Box in the mid-1980s to argue that most problems can be solved with simple tools in the hands of many: 'statistics is too important to be left to the statisticians (only)'.

consulting firm. The broadcast, hosted by Lloyd Dobyns, brought positive attention to the work of statisticians, in particular that of W. Edwards Deming, an American statistician revered in Japan for his help in improving industrial quality after World War II, but not widely known in the US. Demand for Deming's services immediately exploded after the broadcast, and statisticians more broadly were called on to help with industrial quality improvement.

Hunter and Joiner were friends of Deming, and Hunter in 1983 was able to persuade Deming to come to Madison to teach a two-day course on 'The Improvement of Quality, Productivity and Competitive Position' [18]. This course generated much excitement in the City of Madison government. In May of 1984, a pilot project to try Deming's philosophy[§§] was launched at the city's Motor Equipment Division, which had been noted for poor productivity and labor-management relations. By keeping check sheets to track the progress of each vehicle, the mechanics[¶¶] were able to identify, with data, what the slow steps were [19], resulting in 'less cussin' and more discussin' '.[‖‖] The mechanics ultimately gifted the Mayor[***] a $3000 paperweight made from a piston with a valve embedded in it—from a city vehicle that had received no preventive maintenance—, and the preventive maintenance program that had been deleted from the city's budget 20 years before was reinstated.

Box was so impressed by the power of these simple data analyses in the hands of the workers themselves that he concluded that 'statistics is too important to be left to the statisticians (only)'. He spoke often about the democratization of science via the simplest statistical tools (Figure 1). The mood for quality was bright in Madison [20].

4. The Center for Quality and Productivity Improvement

Concurrently with Hunter's work with the City of Madison and Box's investigation of Taguchi methods, the University of Wisconsin approved the formation of the Center for Quality and Productivity Improvement (CQPI) on October 1, 1985. The Center's mission:

> Quality and productivity improvement are multidisciplinary, requiring input from and interaction among many different fields. The Center is located administratively in the College of Engineering and is jointly sponsored by the School of Business and the College of Letters and Science.
>
> The objectives of the Center are
>
> - To conduct vital research in modern methods of quality improvement that cannot be carried through economically by industries on their own
> - To disseminate our findings to industry through reports, publications, seminars, conferences, videotapes, and internships
> - To provide a reliable guide to how managers, engineers, and other personnel should be trained in modern quality techniques
> - To be a forum for the dynamic exchange of ideas among experts in various disciplines from industry and government as well as academia

[§§] *Deming stressed that the quality of a worker's output is inherent in the system and therefore not under the worker's control. Rather, it is up to top management to create a system in which workers can succeed. See Deming's '14 Points for Management'* [21].

[¶¶] *Led by Joe Turner, a foreman in the garage, and Terry Holmes, president of union local 236; under the guidance of Peter Scholtes, a city employee who specialized in organizational development, and Bill Hunter.*

[‖‖] *Joe Turner.*

[***] *F. Joseph Sensenbrenner, Mayor of the City of Madison (1983–1989), was a strong proponent of Deming's approach to quality improvement in the community.*

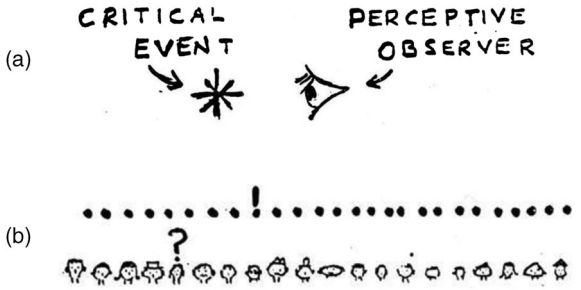

Figure 2. Transparency fragments built up as overlays by Box in the mid-1980s to illustrate (a) that learning occurs when a perceptive observer encounters a critical event, but (b) that informative events are not always aligned with observers who might learn from them–so that informative events need to be encouraged to occur by running designed experiments.

> In these ways, the Center will contribute to the improved functioning and increased success of organizations of all kinds and to increased fulfillment of individuals working in those organizations.

Hunter became the Director of the Center, Box the Director of Research, and Søren Bisgaard, a newly minted PhD under Hunter, a Research Associate[†††].

The Center was fortunate to obtain space shared with the Mathematics Research Center in the Wisconsin Alumni Research Foundation building and was doubly fortunate to hire Judy Pagel from Mathematics Research Center to be the Administrative Assistant for CQPI.

Two weeks later, the entire membership of CQPI flew to New Brunswick, NJ to present a 4-day short course, 'American and Japanese Techniques for Quality Improvement – a distillation and synthesis of the best ideas', under the auspices of the Ellis R. Ott Foundation. This was the first comprehensive offering of Box's past year's work on Taguchi methods, hot off the press, presented with overhead transparencies, which all the speakers had learned, from Box, to cut into small pieces to overlay for a more lively narrative (Figure 2). It drew an overflow crowd of over 100 participants, delighting but also severely taxing the conference hotel.

Disseminating the Center's findings in a more permanent way was also a key mission. To that end, the 'CQPI Report Series in Quality and Productivity' was launched, and the first nine reports issued in February of 1986. 'Report No. 1' was by George Box and Dan Meyer, 'Studies in Quality Improvement: Dispersion Effects from Fractional Designs' (subsequently published in *Technometrics* [22]). Within the first 3 years, 38 reports had been issued and 30,000 copies requested by industry. The reports ranged widely in subject matter, spanning technical expositions, ideas for management, essays of general interest, and case studies. For example, Report No. 13 by Bill Hunter, Jan O'Neill, and Carol Wallen, 'Doing More with Less in the Public Sector: A Progress Report from Madison, Wisconsin' (subsequently published in *Quality Progress* [19]), described how 'new quality improvement ideas can help public officials combat the effects of decreasing budgets just as they help private businesses increase productivity'; and Report No. 38 by Søren Bisgaard, 'Teaching Statistics to Engineers' (subsequently published in *The American Statistician* [23]), pointed out that 'The fact that many engineers have only recently "discovered" statistics suggests that we need to reconsider our approach to teaching this important science.' In this report, Bisgaard reported on his experience teaching engineers 'using an approach that integrates statistics into engineering practice'. Many reports were contributed by guest authors and visitors to the Center[‡‡‡], as well as by successive generations of students.[§§§] The final report to be coauthored by Box was Report No. 180 by George Box and Alberto Luceño, 'Feedforward as a Supplement to Feedback Adjustment in Allowing for Feedstock Changes' (subsequently published in the *Journal of Applied Statistics* [24]). All the reports are available online: http://cqpi.engr.wisc.edu/technical_reports. The cumulative list of reports is a reminder of the exceptionally congenial environment at the Center that had been created by Hunter, Box, and Bisgaard, who sincerely cared for the visitors to the Center and collaborated and became dear friends with many of them.

[†††] *Initial student members included Stephen Jones, José Ramírez, and Conrad Fung.*

[‡‡‡] *Peter Scholtes, W. Edwards Deming, Kaoru Ishikawa, F. Timothy Fuller, William A. Golomski, William J. Hill, Lane Bishop, Spencer Graves, Paul M. Berthouex, Christer Hellstrand, Albert Prat, Xavier Tort, Veronica Czitrom, T. Fearn, P.I. Maris, Neil Diamond, Vijayan Nair, Mikkel Mørup, Alberto Luceño, David Steinberg, Dizza Bursztyn, John Hallinan, W. Lee Hansen, Joe Van Matre, John Tyssedal, Ilya Gertsbakh, Haim Shor, Gunhild Dalen, Marit Ellekjaer, Peder Andersson, M. A. Ilseng, T. Naes, R. G. Wilkinson, Ronald D. Snee, Roger Hoerl, Antonio F. B. Costa, Ian Bradbury, Gipsie Ranney, René Valverde-Ventura.*

[§§§] *Dan Meyer, Conrad Fung, Andrzej P. Jaworski, José Ramírez, Stephen Jones, Mike Hamada, Jesus Juan, Tim Kramer, Ian Hau, Howard Fuller, Bruce Ankenman, Paul Weiss, and Patrick Liu.*

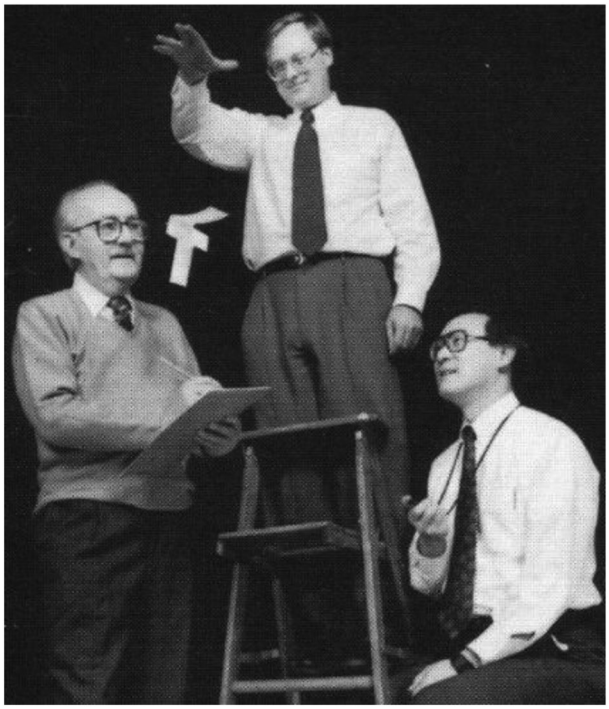

Figure 3. George Box, Søren Bisgaard, and Conrad Fung run a designed experiment with paper helicopters.

Sadly, Hunter's health declined throughout the Center's first year, and he died in December of 1986 at the age of 49.[¶¶¶] The diversity of friends at his service was proof of his connectedness and joy in everyone. He was the intersection of groups that would not otherwise have met, with lasting impact on each.

George Box then became the Director of CQPI.

5. Outreach, fundraising, and recognition in the early years of the Center for Quality and Productivity Improvement

To disseminate the Center's findings in a live and personal format as well as to generate much-needed funding, the Center embarked on a series of short courses with administrative help from the Department of Engineering Professional Development at the University of Wisconsin.

The first course to be offered was 'An Explanation and Critique of Taguchi's Contributions to Quality Improvement', taught by Box, Bisgaard, and Fung in April of 1987. It sold out immediately, a rarity for a statistics class. The presentation was updated with recent learnings about Taguchi methods, but the slides were still painstakingly handwritten. A special treat for the participants was an after-class reception at the home of George and Claire Box in Fitchburg, Wisconsin, to which the group was transported in two school buses. Spirits were high despite the controversial subject matter during the day in the classroom. The reception was such a success that it became an attraction for all the Center's courses until Box's retirement.

The second course was 'Designing Industrial Experiments: The Engineer's Key to Quality', taught by Box, Bisgaard, and Fung in November of 1987. The motive for this course was to start fresh with what one *should* do in designing experiments. A fun element of the course was a live experiment with paper helicopters,[‖‖‖] of which there were 16 configurations to study the effects of eight factors in a 2^{8-4} fractional factorial experiment. Bisgaard climbed a ladder to the ceiling of the classroom to drop the helicopters while Fung emceed and timed each flight (Figure 3). The class was able to see which

[¶¶¶] *Hunter and Box had long been dear friends. Years before, as an undergraduate, Hunter had received permission to attend Box's graduate seminar on experimental design at Princeton—to learn from dittoed handouts that would ultimately become Statistics for Experimenters* [25]. *Hunter said that little did he know then, as a student, that he was learning from a book of which he was to become one of the authors.*

[‖‖‖] *CQPI was grateful to acknowledge the suggestion by C.B. 'Kip' Rogers to use paper helicopters for this purpose.*

factors affected the time, as well as the stability, of each flight. Paper helicopters to teach experimental design have been widely used worldwide ever since. Box wrote of paper helicopters as a teaching device in Box [26], and Box and Liu [27] showed how paper helicopters can be used in a remarkably sophisticated way to demonstrate response surface methods.

There were many repeat performances of the aforementioned two courses.

In the Fall of 1987, Bisgaard and Fung were given fractional appointments in the Department of Industrial Engineering, improving the Center's financial stability. Together, they created and jointly taught two new courses on quality improvement for Industrial Engineering students.

The Center's members and colleagues won many quality-related recognitions in the Center's first few years:

- 1987 *Shewell Award*, to Bisgaard for the best paper at the Fall Technical Conference of the American Society for Quality ('The Quality Detective');
- 1987 *Brumbaugh Award*, to Box and Bisgaard for the best paper in *Quality Progress* ('The Scientific Context of Quality Improvement');
- 1988 *Youden Prize*, to Box for the best paper in *Technometrics* ('Signal-to-Noise Ratios, Performance Criteria, and Transformations');
- 1989 *Best paper at the Annual Quality Congress* of the American Society for Quality, to George Box, Laurel Joiner, Sue Rohan, and F. Joseph Sensenbrenner ('Quality in the Community: One City's Experience'); and
- 1989 *Deming Medal* awarded to Box by the Metropolitan Section of the American Society for Quality.

6. Grants, gifts, cooperation, and progress on many fronts

The Center received major support for research from the National Science Foundation (NSF), the Sloan Foundation, the Vilas Trust for the University of Wisconsin, and Emerson Electric; as well as other welcome gifts from Hewlett-Packard, Alcoa, and General Foods.

Box's initial exploration of Taguchi methods was supported by NSF, partially funded by an Industry/University Cooperative Research Project Grant jointly with AT&T Bell Labs. This resulted in many publications concurrently by Box and by AT&T Bell Labs. In addition, two workshops per year were held, in alternating locations, to share ideas with other workers in this field in industry and academia. Under this grant, CQPI was a joint sponsor of the third and fourth Quality and Productivity Research Conferences (June 1986 and June 1987, respectively, at Oakland University).

Box summarized his research focus as follows[****]:

> Because industrial experimentation is usually expensive, emphasis is given to techniques and strategies which minimize experimental effort, [††††] and maximize information gained from analysis of results. [‡‡‡‡] Central topics are: reduction of variation; designing products robust to environmental variation; [§§§§] and modeling control processes to achieve better understanding of the roles and possible conflicts between statistical process control (SPC) and automatic process control (APC).[¶¶¶¶]

Progress was indeed made on many fronts during these few years:

Resolution of Taguchi methods—After a decade of study by many investigators, a definitive paper on theoretical understanding of Taguchi methods was published: 'Taguchi's Parameter Design: A Panel Discussion' edited by V.N. Nair [4] with discussants George Box and others.

Design of robust products—Expanding on Taguchi's important concept of parameter design, Box and Jones [9, 10] investigated the design of products that are insensitive to environmental variation. Of particular importance was the efficiency of split-plot designs: experiments conducted in split-plot mode can be of great value in robust product design because they not only enable the contrasts of interest to be estimated efficiently, but the experiments can be easier

[****] *Quoted from a request by Box for renewal of a grant from NSF, February 1989.*

[††††] *Dispersion effects, location effects and signal-to-noise ratios; projective properties of design; sequential assembly of designs.*

[‡‡‡‡] *Bayes analysis of fractional factorials; data transmission and designed experiments in life testing; analysis of ordered categorical data and accumulation analysis; sequential assembly of designs.*

[§§§§] *Robust product and process design.*

[¶¶¶¶] *SPC and APC control schemes.*

to conduct than fully randomized designs. [IIIIII] Box and Fung [12] studied the design of products that are insensitive to variation transmitted from their own components. 'Optimal' product configurations can be found easily when a mathematical model for the product is known, but the authors pointed out that parameter design solutions can be very sensitive to assumptions that are made about the dependence between the random variation in a design variable and its intended value; therefore, verification of assumptions is a vital part of parameter design.

Statistical design of experiments—Box and Hau [30] developed new results in the design and analysis of experiments where the variables are subject to multiple linear constraints. They proposed a class of *projection designs* and showed how analysis of such designs can be carried out using essentially the same methods as are used for unconstrained designs such as factorials and composite designs, vastly simplifying the calculations required for modeling. [*****]

Process control—Box and Kramer [33] and Box and Luceño [34] studied the optimal design of process control from an economic point of view. Box and Kramer provided a unifying parametric model to understand the controversy which is often found in industry concerning the appropriate roles for Statistical Process Control versus Automatic Process Control. They showed how the many standard schemes, such as Shewhart Charts, cumulative sum charts, exponential charts, proportional-integral feedback control, and various feedforward schemes, are appropriate or inappropriate depending on the answers to a variety of questions—including the costs of observing and adjusting the process, the cost of being off target, the process's dynamics, and the nature of the noise in the system—each of which implies different choices for the parameters in the unifying parametric model. Box and Luceño investigated a cost model for obtaining minimum cost for feedback control and provided charts to aid the choice of an appropriate scheme. To communicate important concepts of control to engineering practitioners, Box [35–38] wrote accessible presentations of technical developments on exponential smoothing, feedback control, and bounded adjustment.

Sequential methods—Box and Ramírez [39] developed a new sequential approach to monitoring of process variability employing a cumulative score statistic (a cumulative version of Fisher's score statistic) and showed how the resulting procedures relate to Wald–Barnard sequential tests and to cumulative sum statistics.

Novel data analysis—Box and Meyer [40] developed a Bayesian method for determining the posterior probability that a factor studied in a fractional experiment is active, while allowing for the possibility of interactions. Important factors involved with such interactions may otherwise go unidentified when conventional methods of analysis are used. This paper won the Brumbaugh Award for 1993. [†††††]

Statistical methods in quality improvement—Box wrote many expository articles to serve audiences in other fields in science and engineering. Box [41, 42] are wide-ranging treatises on creativity, learning, and experimental design for industrial process improvement. Box [43, 44] give overviews of the role of statistics and scientific method in investigation and discovery, and discuss implications for management. Box [45–48] discuss a variety of issues in the design and analysis of experiments, in particular: the importance of interactions, the importance of randomization, dealing with missing observations, and finding bad data values in factorial designs. Box [49–51] discuss economy in experimentation, employing 8-run, 16-run, and sequentially-assembled designs. Box [26] and Bisgaard [23] give practical advice on teaching statistics and experimental design to non-statisticians. Bisgaard [52] presents a case study of quality improvement in manufacturing. [‡‡‡‡‡] Box [53] is an entertaining yet profound consideration of 'Murphy's Law' and its implications for quality improvement. [§§§§§]

With his prodigious theoretical output, his many popular articles for engineering practitioners and lay readers, and frequent engagements in the community, it was an era of extraordinary productivity and connectedness for Box.

[IIIIII] *Paniagua-Quiñones and Box* [28, 29] *later studied strip-strip-block designs for multistage processes to reduce costs of experimentation.*
[*****] *Box and Tyssedal* [31, 32] *later studied projective properties of orthogonal arrays as a motivation for fractional experiments.*
[†††††] *This was Box's second Brumbaugh Award.*
[‡‡‡‡‡] *A live presentation of this case study won the Shewell Award for Bisgaard in 1987.*
[§§§§§] *Murphy's Law says that anything that can go wrong, will go wrong. Box was amused to note that his name was missing from the title page of the published article.*

7. Retirement in name only

Box departed Madison in 1990 for a year's leave [¶¶¶¶¶] at Stanford's Institute for Advanced Study in the Behavioral Sciences and retired from the University of Wisconsin upon his return in 1991. Yet, he was still at the peak of his era of quality and productivity!

During retirement, Box formed a deep friendship with Alberto Luceño and his family, who visited Madison from Santander, Spain, for the 1991–1992 academic year. George and Claire Box subsequently made two year-long visits to Santander. Box and Luceño's collaboration over the next decade produced seminal papers on process control, bringing together key elements of statistical control with techniques of feedback adjustment [24, 34, 54–56]. [‖‖‖‖‖‖] Their work through 1997 was published in book form [57], and an updated edition of the book was published in 2009 [58]. See the article by Woodall and del Castillo in this issue of *ASMBI*.

Box's focus on control during this era produced two further papers that clarified for practitioners the importance of recognizing non-stationarity in processes when attempting to monitor and control them: Box and Paniagua-Quiñones [59] and Box and Narasimhan [60], which won Box's fourth and fifth Brumbaugh Awards.

8. A legacy of never-ending improvement

Box celebrated his 80th birthday in October of 1999. On that occasion, his good friends and colleagues, George C. Tiao, Søren Bisgaard, William J. Hill, Daniel Peña, and Stephen M. Stigler,

> . . . asked Professor Box if he'd like to sort through his papers and perhaps add a few words. He agreed and has selected, extracted, and arranged these in logical order to form the chapters of this book (*Box on Quality and Discovery*, 2000). We now have vignettes of his thoughts, reminiscences of earlier days, and renewed insights. [******]

Box updated the book in 2006 and aptly changed the title to *Improving Almost Anything*. [††††††] Indeed,

> The book is divided into six parts. The first of these are directed to managers, another to those who would apply experimental design, another for those who study and work in experimental design, a group encouraging the flirtation between control engineering and statistics, a group devoted to variance reduction and the concept of robustness and, finally, some of his songs. [‡‡‡‡‡‡]

Box was uniquely original and theoretically powerful, yet was a masterful communicator who could distill sophisticated concepts to fundamental nuggets that are accessible to workers who face practical problems. That the quality movement brought such a remarkable convergence of interest to so many distinct fields that were pioneered by Box is a testament to the truth that the notion of improvement is statistical in its essence—that with a statistical outlook, one can improve almost anything; and that in the hands of George Box, one is better equipped to do so.

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[¶¶¶¶¶] *William J. Hill, who received his PhD under Box in 1966, became the Director of CQPI in 1991. Søren Bisgaard became Director in 1992. From 1999 onwards, CQPI has been refocused to apply '. . . the principles of human factors and systems engineering to improve the quality and safety of work processes, working life, and health care', under Prof. Pascale Carayon.*

[‖‖‖‖‖‖] *Box and Luceño* [55] *won the Brumbaugh Award for 1997, Box's third.*

[******] *Quoted from the Foreword by J. Stuart Hunter in Box* [61]*).*

[††††††] *Box* [62].

[‡‡‡‡‡‡] *Quoted from the Foreword by J. Stuart Hunter in Box* [62].

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