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(*b*. Townsville, Australia, 12 April 1900: *d*. Washington, D.C., 31 March 197 1)

*mathematical statistics*.

Youden was the eldest child of William John Youden, an English engineer, and Margaret Hamilton of Carluke, Scotland. In 1902 the family returned to the father's birthplace-Dover, England-and resided there until 1907, when they left for America. They lived for a while in Connecticut and at Niagara Falls, New York, where Youden attended public school, before moving to Rochester, New York, in 1916. Youden attended the University of Rochester from 1917 to 1921, except for three months in the U.S. Army in 1918, receiving a B.S. in chemical engineering in 1921. He began graduate work in September 1922 at Columbia University, earning an M.A. in chemistry in 1923 and a Ph.D. the following year.

Immediately after receiving his doctorate, You-den joined the Boyce Thompson Institute for Plant Research in Yonkers, New York, as a physical chemist. He held this post until May 1948, when he joined the National Bureau of Standards as assistant chief of the Statistical Engineering Laboratory, Applied Mathematics Division. Three years later he became a consultant on statistical design and analysis of experiments to the chief of this division, a position he retained until his retirement in 1965 .

He was an honorary fellow of the Royal Statistical Society (1965), and was awarded the Medal of Freedom in 1964, the 1969 Samuel S. Wilks Memorial Medal of the American Statistical Association, and the 1969 Shewhart Medal of the American Society for Quality Control .

In 1922 Youden married Gladys Baxter of Rochester, New York : they had two sons, William Wallace (1925- 1968) and Robert Hamilton, both of whom chose careers in the computer field. In 1938 he married Grethe Hartmann of Copenhagen, Denmark: they had one son, Julius Hartmann, now a teacher in Copenhagen. In 1957 Youden married Didi Stockfleth of the Norwegian Embassy staff in Washington, D.C. Survivors of his immediate family include his widow, Didi; two sons; and eight grandchildren. Youden is buried in the National Cemetery, Gettysburg National Military Park, Gettysburg, Pennsylvania, in deference to his expressed wishes to remain in his adopted country .

Youden began his professional career as a physical chemist. His first paper to exhibit any knowledge of statistical methods, "A Nomogram for Use in Connection With Gutzeit Arsenic Determinations on Apples" (September 1931), was expository in nature : he noted that the differences between repeated determinations of a physicochemical property of a particular biological material reflect not only the "probable error" of the method of chemical analysis but also the "probable error" of the technique of sampling the material under investigation, and then, with guidance from a 1926 paper of W. A. Shewhart, outlined the requisite theory, illustrated its application, furnished a nomogram to facilitate correct evaluation of the precision of a particular procedure, and pointed out statistical errors that marred a number of earlier publications on sampling of apples for determination of arsenical sprayed residue. This paper marks the beginning of Youden's "missionary" efforts to acquaint research workers with statistical methods of value in their work.

About 1928 Youden "obtained one of the 1050 copies…of the first edition" of R. A. Fisher's Statistical Methods…(1925). At that time he was "so discouraged by what was called 'measurement' in biology that [he] was on the point of resigning" his post at Boyce Thompson. "Fisher's book opened a ray of hope," however, and Youden soon realized that at Boyce Thompson "he had the opportunity to perform agricultural experiments, both in the field and in the greenhouse, and to try out the early experiment designs" and Fisher's new small-sample methods of data analysis . The publicity for the visit of Fisher to Iowa State College in 1931 came to Youden's attention and aroused his curiosity, but he was unable to attend . When Fisher visited Cornell on his way home from Iowa, Youden "drove there …to show him an experimental arrangement."[1] During the academic year 1931-1932, he commuted to Columbia University to attend Harold Hotelling's lectures on statistical inference.[2]During the next few years he published a number of mathematical-statistical papers describing the application of statistical techniques to problems arising in studies of seeds, soils, apples, leaves, and trees .

During this period Youden devoted increasing attention to statistical design of experiments, in order to cope with the enormous variability of biological material ; he found many of the standard experiment designs developed for agricultural field trials to be directly applicable in greenhouse work, a situation that led to vastly improved precision . Recognizing that the limited number of leaves per plant thwarted the use of Latin square designs to effect precise within-plant comparisons of a large number of proposed treatments for plant ailments, Youden devised new symmetrically balanced, incomplete block designs that had the characteristic "double control" of Latin square designs but not the restriction that each "treatment (or "variety") must occur once, and only once, in each row and column. He brought these new designs to R . A . Fisher's attention in 1936 and subsequently completed "Use of Incomplete Block Replications in Estimating Tobacco Mosaic Virus" (1937), in which he

presented and illustrated the application of four of the new rectangular experimental arrangements. In a subsequent paper (1940) he gave eight additional designs and, for six of these, the complementary designs . Youden's new rectangular experiment designs, called "Youden squares" by R . A . Fisher and F. Yates in the introduction to their Statistical Tables …(1938, p . 18), were immediately found to be of broad utility in biological and medical research generally ; to be applicable but of less value in agricultural field trials ; and, with the advent of World War II, to be of great value in the scientific and engineering experimentation connected with research and development . To gain further knowledge of statistical theory and methodology, Youden audited the courses on mathematical statistics and design of experiments, by Harold Hotelling and Gertrude M . Cox respectively, and took part in a number of statistical seminars at North Carolina State College in 1941 .

Youden served as an operations analyst with the U .S. Army Air Force (1942-1945), first in Britain, where he directed a group of civilian scientists seeking to determine the controlling factor in bombing accuracy ; in the latter part of the war, he conducted similar studies in India, China, and the Marianas, preparatory to the assault on Japan . He displayed exceptional skill in the invention of novel, and adaptation of standard, statistical tools of experiment design and analysis to cope with problems arising in the study of bombing accuracy .

In a lecture delivered at the National Bureau of Standards in 1947 Youden exposed the fallaciousness of the all-too-common belief that statistical methods-and a statistician-can be of no help unless one has a vast amount of data ; demonstrated that one can obtain valuable information on the precision-and even on the accuracy-of a measurement process without making a large number of measurements on any single quantity ; and showed how in routine work one can often obtain useful auxiliary information on personnel or equipment at little or no additional cost through skillful preliminary planning of the measurements to be taken .

On joining the National Bureau of Standards in 1948, Youden revealed the advantages of applying carefully selected statistical principles and techniques in the planning stages of the Bureau's experiments or tests. In the course of these demonstrations he noticed, and was one of the first to capitalize on, important differences between experimentation in the biological and agricultural sciences and in the physical and chemical sciences.[3]

Youden began to devise new forms of experimental arrangements, the first of which were his "linked blocks" (1951) and "chain blocks" (1953), developed to take advantage of special circumstances of spectrographic determinations of chemical elements carried out by comparing spectrum lines recorded on photographic plates.[4] In 1952 Youden and W. S . Connor began to exploit a special class of experiment designs having block size 2 in the thermometer, meterbar and radium-standards calibration programs of the Bureau . The thermometer calibration application involved observation of the reading of each of the two thermometers forming a "block" ; the meterbar application involved observation of only the difference of the lengths of the two meter bars making up a block, and marked the start of the development of a system of "calibration designs" that Youden did not develop further and exploit as a special subclass until 1962: and the radium-standards application, observation of only ratios of pairs of standards . Meanwhile, Youden and J. S. Hunter had originated a class of designs that they termed "partially replicated Latin squares" (1955), to provide a means of checking whether the assumption of addi-tivity of row, column, and treatment effects is valid. In an epochal 1956 address, "Randomization and Experimentation," Youden introduced a technique for constrained randomization that obviatesx "the difficult position of the statistician who rules against …a systematic sequence when advanced on the grounds of convenience and insists on it when it pops out of the hat" (p.16).

In the early 1960's Youden exploited a class of selected experiment designs with the specific purpose of identifying and estimating the effects of sources of systematic error. "Systematic Errors in Physical Constants" (1961) contains his first "ruggedness test" based on the observation that some of the fractional factorial designs, developed a decade earlier for optimum multifactor experiments, were ready-made for testing the "ruggedness" (insensitivity) of a method of measurement with respect to recognized sources of systematic error and changes of conditions likely to be encountered in practice.

Youden also originated at least three new statistical techniques: an index for rating diagnostic tests (1950), the two-sample chart for graphical diagnosis of interlaboratory test results (1959), and an extreme rank sum test for outliers (1963), devised to test the statistical significance of outlier laboratories in interlaboratory collaborative tests. The two-sample chart has the same advantage as Shewhart's control chart: simplicity of construction, visual pinpointing of trouble spots, and comparative ease of more refined analysis.[5] Although developed in the setting of test methods for properties of materials. ithas become a standard tool of the National Conference of Standard Laboratories in its nationwide program of searching for and rectifying systematic differences in the most accurate programs for instrument calibration.[6] This technique is now used in all measurement fields where interlaboratory agreement is important, and the term "Youden plot" specifies not only the plotting technique but also the experimental procedure for sampling the performance of each laboratory through the results obtained on paired test items [7]. In the case of the extreme rank sum test, Youden's ideas had been anticipated by R. Doornbos and H. J. Prins (1958), but it was characteristic of Youden that he had independently conceived his test primarily as a device to dramatize and clarify the messages contained in experimental results, rather than as a contribution to distribution-free statistical methods.

By his publications and by his example, Youden contributed substantially to the achievement of objectivity in experimentation and to the establishment of more exact standards for drawing scientific conclusions. "Enduring Values," his address as retiring president of the Philosophical Society of Washington, is an exposition of schemes for incorporating investigations of systematic errors into experimental determinations of fundamental physical constants and a plea for efforts by scientists to accumulate objective evidence for the description of the precision and accuracy of their work. Shortly before his death Youden completed the manuscript of another "missionary" effort, *Risk, Choice and Prediction* (1974), formally intended to familiarize

students in the seventh grade and above with basic statistical concepts but actually meant "for anyone…who wants to learn in a relatively painless way how the concept and techniques of statistics can help us better understand today's complex world" (p. vii).

# NOTES

1. The first and last quotations are from W. J. Youden, "Memorial to Sir Ronald Aylmer Fisher," in *Journal qt the American Statistical Association*. 57, no. 300 (Dec. 1962).727: the others, from Youden's "The Evolution of Designed Experiments," 59.

2. At this time Hotelling was the person in the United States most versed in the Student-Fisher theory of small samples.

3. Of paramount importance, he noted, is the difference in the magnitude of the errors of measurement: in agricultural and biological experimentation unavoidable variation is likely to be large, so the early experiment designs developed for application in these fields compensate by incorporating many determinations of the quantities of principal interest: physical measurements, in contrast, can often be made with high precision and the experimental material usually is comparatively homogeneous, so that the quantities of interest often can be determined with acceptably small standard errors from as few as two or three, or even from a single, indirect determination. Also, in many experimental situations in the physical sciences and engineering, a "block" and the "plots" within a block are sharply and naturally defined, and often are quite distinct: this is in marked contrast with the arbitrary division of a given land area into "blocks" in agricultural field trials, and the subdivision of a block into contiguous "plots." Consequently, various "interactions" commonly present in agricultural field trials are often absent or negligible in physical-science experimentation.

4. "Linked block" designs are incomplete block designs for which every pair of blocks has the same number of treatments in common; the were subsequenly shown to be special cases of partially balanced incomplete block designs with two associate classes to triangular type. "Chain blcok" designs were developed for situation in which the number of treatments considerably exceeds the block size while, within blocks, comparisons are of such high precision that at most two replications are needed, some treatments occurring only once. Chain block design with two-way elimination of heterogeneity were subsequently devised by Manel (1954).

5. See, for example, Acheson J. Ducan, *Quality Control and Industrial Stratistics,* 3rd ed. (Homewood, III., 1965), pt. 4.

6. See *Proceedings of the 1966 Standards Laboratory Conference,* National Bureau of Standars Miscellaneous Publication 291 (Washington, D. C. 1967), 19, 20 27–29, 42, 45, 48, 51, 61, 62.

7. "Graphical Diagnosis of Interlaboratory Test Results" (May 1959) is the basic reference on the "Youden plot." A condenswed appeared in *Technical News Bulletin. National Bureau of Standards*.**43** no. 1. (Jan. 1959), 16–18: and its evolution can be followed in four columns coulmns in *Industrial and Engineering Chemistry:* "Presentaion for Action," *no. 8 (Aug. 1958). 83A–84A:* "Product Specifications and Test Procedures," *ibid*.,no.10 (Oct. 1958), 91A–92A "Circumstances Alter Cases," ibid ., no. 12 (Dec. 1958), 77A–78A: and "What Is Measurement?" **51** no. 2 (Feb. 1959), 81A–82A.

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Youden's doctorl dissertation, *A New Method for the Gravimetric Dtermination of Zirconium,* was privately prined (New York, 1924), As a member of the staff of the Boyce Tompson Institute, he published 15 research papers on chemical and biological studies and instrumention pertinet to the work of the Institute in *Contributions From Boyce Tompson Institute* The items below that are marked "repr. in JQT" were reprinted in *Journal of Quality Technology*,**4** no. 1; and those marked "repr. SP 300–1," in Harry H. ku. ed., *Precision Measurment and Calkibration: selected Papers on Statistical Concepts and Procedures,* National Bureau of Standards Special Publication 300, vol. 1(Washington, D. C., 1969).

Youden's earlier works include "A Nomogram for Use in Connection With Gutzeit Arsenic Determinations on Apples," ion *Cobtributions From Boyce Thompason Institute*,**3** no. 3 (Sept. 1931), 363–373; "Statistical Analysis of Seed Germination Data Through the Use of the Chi Squre Test," *ibid*.,**4** no. 2 (June 1932), 219–232; "A Statistical Study of the Local Lesin Method for Estimating Tobacco Mosaic Virus, Concentration to the Number of Lesions Produced," *ibid***6** no. 3 (July Sept. 1934), 437–

454. written with Helen P. Beale; "Relation of Virus Concentration to the Number of Lesions Produced," *ibid*.,**7** no. 1 (Jan-Mar. 1935), 317–331, written with P. W. Zimmerman; "Use of Incomplete Block Replications in Estimating Tobacco Mosaic Virus," *ibid*.,**9** no. 1 (Nov. 1937), 41–48 (repr. in *JQT*), the paper in which the frist four members of a new class of rectangular experimental arrangemnets, now called "Youden squares," appeared—the paper that catapulted him to fame; "Selection of Efficeint Methods for Soil Sampling," ibid., 59–70; "Experimental Designs to Increase the Accracy of Greenhouse Studies" ibid., **11** no. 3 (Apr.- June 1940), 219–228; "Buretter Experiment," part of the lecture "A Statistical Technique for Analytical Data," delivered at the National Bureau of Standards, 29 Apr. 1947, repr. in JQT from pp. 344–346, 350, of Churchiloll Eisenhart, "Some Canons of Sound Experimentation," in *Bulletin de l'Institut international destatistique*,**37** no. **3** (1960), 339–350; and "Technique for Testing the Accuracy of Analytical Data," in *Analytical Chemistry*,**19** no. 12 (Dec. 1947), 946–950.

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See also *Statistical Design* (Washington, D.C., 1960), a collection of 36 articles published in a column with this title in *Industrial and Engineering Chemistry*,**46** no. 2 (Feb. 1954)–**51** no.12 (Dec. 1959); "Physical Measurements and Experiment Design," in *Colleques internationaux du Centre national de la recherche scientifique* (Paris,1961), no. 110, le Plan d'Experiences, 115–128 (repr. in *SP-300–1);* "Systematic Errors in Physical Constants," in *Physics Today*,**14** no. 9 (Sept. 1961), 32–42, repr. in *Technometrics*,**4** no. 1 [Feb. 1962], 111–123, and in *SP-300–1;* "Experimental Design and ASTM Committees," in *Materials Research and Standards*,**1,** no. 11 (Nov. 1961), 862–867 (repr. in *SP*-300–1); *Experimentation and Measurement* (New York, 1962); "Uncertainties in Calibration," in *I. R. E. Transactions on Instrumentation,* 1–11, nos. 3–4 (Dec. 1962), 133–138 (repr. in *JQT* and *SP-300–1* "Ranking Laboratories by Round-Robin Tests," in *Materials Research and Standards*,**3** no. 1 (Jan. 1963), 9–13 (repr. in *SP-300–1); "Measurement Agreement Comparisons," in Proceedings of the 1962 Standards Laboratory Conference. National Bureu of Standards Miscellaneous Publication 248* (Washington, D. C., 1963), 147–151 (repr. in *SP-300–1),* the paper that inspired the work of Bose and Cameron (1965,1967) and Eicke and Cameron (1967) on "calibration designs." "The Collaborative Test," in *Journal of Association of Official Agricultural Chemists*,**46** no. 1 (Feb. 1963), 55–62 (repr. in *SP-300–1);* and "The Evolution of Designed Experiments, "in *Proceedings of the [1963] IBM Scientific Computing Symposium on Statistics* (While Plains, N. Y., 1965), 59–67 (repr. in *JQT*

Additional works are *Statistical Techniques for Collaborative Tests* (Washington, D.C., 1967); "How Mathematics Appraises Risks and Gambles," in T. L. Saaty and F. J. Weyl, eds., *The Spirit and Uses of Mathematics* (New York, 1969), 167–187: "A Revised Scheme for the Comparison of of Quantitative Methods," in *American Journal of Clinical Pathology*,**54** no. 3 (sept. 1970), 454–462, written with R.N.Barnett; "Enduring Values," in *Technometrics,***14** no. 1 (Feb. 1972), 1–11; "Randomization and Experimentation," *ibid*., 13–22; and *Risk, Choice and Prediction: An Introduction to Experimentation* (North Scituate, Mass., 1974).

Copies of all of Youden's journal articles and book reviews, and many of his book chapters, published in 1924-1965, are bound together, generally in chronological order, along with copies of his Air Force manuals, his patents, and his paperbound books *Statistical Design* and *Experimentation and Measurement*, in "W. J. Youden Publications," 2 vols., in the Historical Collection of the Library of the National Bureau of Standards at Gaithersburg, Md. His publications of 1966-1972 have been assumbled for a 3rd vol. There is also a vol. containing abstracts of his talks given during 1949-1965. In addition, among the records of the Bureau's Applied Mathematics Division are eight boxes of "Youdeniana" covering 1920-1971: personal records given by his widow in 1973, professional correspondence, reports, commendations, certificates of awards, photographs, handwritten notes and computations, and a considerable number of Youden's papers, lectures, and speeches.

II. Secondary Literature. Youden's career and contributions to statistical theory and practice are summarized briefly in an unsigned obituary in *American Statistician,***25** no. 3, (June 1971), 51: and more fully by Churchill Eisenhart, in *Journal of Quality Technology*,**4** no. 1 (Jan. 1972), 1–6 His contributions to the theory of statistical design and analysis of experiments are given special attention by Churchill Eisenhart and Joan R. Rosenblatt, in *Annals of Mathematical Statistics*,**43** no. 4 (Aug. 1972), 1035-1040. A biography of Youden, with portrait, is scheduled for publication in *National Cyclopedia of American Biography,* LVI (1975), 99–100. A biographical essay on Youden's contributions to statistical theory, methodology, by Harry H. Ku is to appear in a volume tentatively titled *Statistics: Articles From the Internatiojnal Encyclopedia of the Social Sciences* (New York, 1976 or 1977).

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Churchill Eisenhart