ChE educator

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OF CONNECTICUT

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C + O + B → Many Active Sites

That equation is not about carbon, oxygen and boron; it is about a man whose initials are COB, whose friends and acquaintances often call him CO and who does research on the catalytic chemistry of CO.

"He's a rare blend of humanist and scientist. If fate had rolled the dice a bit differently, he might have been equally productive as an English professor instead of as a chemical engineer."

These are the words of a professor of chemical engineering at a midwestern university talking about one of his former teachers, Carroll O. Bennett of the University of Connecticut. Another chemical engineering professor described Bennett as "one of the most liked chemical engineers in the country." Add to that the lasting influence of his co-authored textbook, "Momentum, Heat, and Mass Transfer," first published in 1962 and still a world-wide standard classroom and reference work, and it is no surprise that Bennett's selection for the 1980 Warren K. Lewis Award was greeted so enthusiastically.

For the modest, soft-spoken chemical engineering professor, the path to the AIChE's highest award for chemical engineering education is especially poignant. This is because it puts him directly in the footsteps of one of the great influential teachers in his own life, Yale chemical engineering professor, Barnett F. Dodge, who won the first Lewis Award back in 1963.

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Bennett's path to the prize led him through a career that penetrated areas as diverse as meteorology and engineering design, and led to journeys on four continents. Along the way he became a gourmet, a lover of fine art and music, and fluent in four languages.

Born in New Britain, Connecticut's "hardware city," Bennett grew up as an only child. Even in high school, Bennett found he had an interest in chemistry, but also found himself drawn to the study of languages, doing well in the study of Latin, French, and German. Influenced by the reality of the depression, however, he continued his studies at Worcester Polytechnic Institute and by the end of his freshman year had chosen to

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study chemical engineering. After receiving his degree in an accelerated program in 1943, he entered the Army Air Corps.

Returning to Connecticut after the war, Bennett worked for a while as a metallurgist before deciding to continue studies in chemical engineering. Bennett spent three years at Yale, receiving his doctorate in 1950. At Dodge's suggestion, he did his thesis research in the area of high pressure thermodynamics. "I studied the compressibility of mixtures of hydrogen and nitrogen up to pressures of 3,000 atmospheres. It was rather interesting work, with a lot of mechanical technique involved." Yale, of course, was where J. Willard Gibbs had done much of his pioneering work on thermodynamics at the end of the 19th century, and his influence was still strong at Yale when Bennett was there.

At the same time, Bennett kept up his interest in French, taking courses in French literature with Henri Peyre, ". . . who is very well known to anybody who knows anything about French literature. I also went to lectures in art history by Vincent Sculley, who is another shining light at Yale," Bennett recalls. Both of these interests were to reemerge later and influence his career and life.

Bennett remembers Dodge "as a man of great intelligence with a very special personality. He was quite austere to students." He recalls the weekly meetings he had with Dodge to discuss his progress on his thesis; "I would go in there and sit down in the chair, and he would look at me and I was supposed to start telling him what I had done. He would ask a few questions. I was always afraid I would say something wrong. I don't know whether Dodge did this purposely or not, but it was very effective. I was always prepared for my weekly meetings." While Dodge seemed somewhat distant at the time, Bennett says he realized later that the professor "was a man of all sorts of human characteristics. Of course, one never realizes that about one's professors."

Even though doctoral research in chemical engineering was not at all common back in those Yale days, Bennett knew he would stick with chemical engineering rather than switch to chemistry. "I didn't want to become a chemist because I didn't want to stay in the lab," he says. "I wanted to do things on a bigger scale, and the scale-up process—going from the small scale you have in the laboratory to the large scale you have in a chemical plant—interested me." But Bennett did not immediately go out into the field and scale up chemical plants. Instead he went into teaching at Purdue.

"When you go into a career as a teacher in engineering, there are two parts to it," according to Bennett. "One is the engineering part, which emphasizes teaching undergraduates, so they can go out and practice engineering the way MD's go out and practice medicine. The other part of one's life in being a university teacher is doing research."

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Looking back on that era, Bennett comments that there were many engineering problems then for which the solutions were not as clear as they are now. "When I was just starting out in the '50's, it became clear that chemical engineers would probably become more interested in fundamental research which would be more similar to research done in physical chemistry than to research done in engineering." Thus he started his research with Prof. Dodge in the basic area of thermodynamics. While the work did not have an immediate practical application in view, it was related to the fact that Dodge, along with others, was interested in solving problems connected with synthesizing ammonia from nitrogen and hydrogen. Dodge wanted to find a way of running the process at high pressure and temperature, so that no catalyst would be needed. Ultimately, Dodge's high temperature and high pressure process proved uneconomic, and now Bennett's research pursues the opposite approach: exploring low pressure and low temperature reactions using catalysts. Bennett finished his work with Dodge in the summer of 1949, about the time he began to realize that teaching might be interesting.

After considering various teaching offers, Bennett selected Purdue University where he started teaching thermodynamics, sharing the course with Prof. Joe M. Smith. Smith had just finished his book on the subject, and was even then a well-known teacher and researcher in chemical engineering. Smith had studied with Warren K. Lewis at MIT and had picked up Lewis' Socratic method of teaching.

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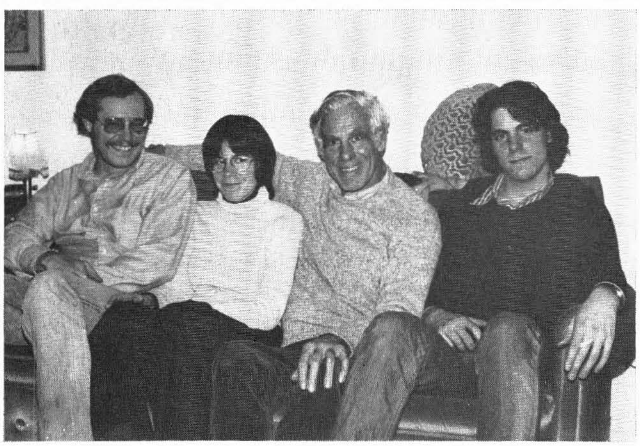
A year later another young instructor, Jack Myers, came from Michigan to join the Purdue faculty. Myers eventually became Bennett's co-author on the now-famous textbook. Bennett and Myers started thinking about the book in the mid to late '50s, began it about 1959, and published it in 1962, after Bennett had left Purdue for a stint in private industry. The book represented a new viewpoint on what the profession was really about.

In the old days, Bennett explains, engineers were associated with specific industries. Thus, there were sugar engineers, petroleum engineers, sulfuric acid engineers, and so on. Then, Lewis and Walker and others at MIT began to develop the idea of organizing chemical engineering in terms of "unit operations." These operations, such as distillation, extraction, absorption, and others,



CO relaxing with his children Edward, Elizabeth and Jonathan, after a skiing trip, in France.

were common to all sorts of chemical engineering processes. Thus, training a person in "unit operations," would enable him to go out and work in any one of the chemical industries.

That approach grew in strength and persuasiveness until it became increasingly clear that, behind the unit operations, there were really only a few basic divisions of the subject grouped around the concepts of heat, mass, and, momentum transfer. "We wanted to unify the unit operations which had previously unified the various different processes in chemical engineering, but to unify them as being manifestations of the principles of heat transfer, mass transfer, and momentum transfer," Bennett says.

At the same time, the computer revolution was just getting under way. "The first computers of any practicality began to be used in the '50s, and it became clear that it was practical to use more mathematics than you could previously," he notes. "You could solve certain differential equations or partial differential equations, or certain multi-component problems that previously would have been impractical to solve by hand because it would take too long, and you probably would make too many mistakes before you got through. The computer created an atmosphere where the fundamental approach became more attractive or more practical, and this, too, influenced the book."

While he was working on the book, and continuing his research on high pressures, mass transfer, and heat transfer, Bennett began to feel he would like to be a practicing engineer for a while. So in 1959 he left Purdue to join the Lummus Co. in New York as a development engineer. In the five years he was there, he worked hard to develop an independent design capability for the company, which previously had generated much of its business by using licensed processes developed by other companies.

"Dr. Bennett played a key role in establishing the research and development department at the Lummus Co., and the basic philosophies and approach which he established have been fundamental to the growth of this effort," according to a senior vice president at CE-Lummus, who added, "His spirit of free investigation and the practical application of fundamentals have contributed to the development and commercialization of a number of important processes." A former vice president for research and development at CE-Lummus noted that Bennett's association with Lummus was mutually beneficial and stated, "The Lummus Co. benefited in the early adoption of computer calculation techniques for chemical engineering design. Professor Bennett benefited in knowing how industry performs its work and what industry needs. No doubt such a combination has helped him to inspire his students and colleagues to high achievement."

Bennett's years at Lummus confirmed his belief that he was on the right track in returning to fundamentals as the basis of teaching chemical engineering. "It convinced me that a person who is intelligent and knows fundamental principles can go right in and compete with people who are experienced engineers, and who perhaps know how to do certain things, but don't remember or never had the fundamental principles, so that their adaptability and flexibility are limited," he observes. "When improvements come along, or new processes or new situations develop, often the people with rusty fundamentals are not able to cope with them and design something suitable." He adds, too, that his teaching has been enhanced by the practical examples he can draw from his industrial experience, and he includes such problems in his lectures, his exams, and in his book.

CO and his wife, Jean, on a night out in Storrs.

It was from Lummus that Bennett came back to education, to the University of Connecticut, in 1964. And it was at UConn that Bennett's interest began to shift into the design of chemical reactors and heterogeneous catalysis. The field was not entirely new to Bennett, since some of his work at Lummus involved catalytic reactions, and many industrial processes are based on catalysts. "Nevertheless, catalysis was always thought of as a sort of black art and there seemed to be a lot of room for increased understanding. It seemed to be a good thing to study," Bennett reflected.

Bennett's elucidation and advocacy of the transient method for catalytic studies has helped to dispel some of the blackness of the catalytic art. This approach allows simple experimentation to shed light on the rich complexity of even the simplest catalytic reactions.

Following pioneering experiments by Wagner in 1938 and further work by Tamaru in 1963, Bennett laid out a quantitative framework in 1967 [AIChE Journal *13*, 890 (1967)]. Later Kobayashi and Kobayashi and Yang et al. implemented this approach, thereby bringing to full fruition the earlier emphasis by Wagner and Tamaru on measuring adsorption during catalysis.

Although transient experiments have long been applied in other fields, only within about the last 10 years have they found wide acceptance in heterogeneous catalysis. As recently as 1975, chemical engineers modelled reactors using steady-state rate expressions rather than models based on elementary steps and their individual rates which can change in response to changing conditions during transients.

Because transient experiments must be purged of the influences of transport resistances, Bennett became an early designer of gradientless reactors, which were forerunners of the now well-known Berty reactor. Later, Bennett applied transient methods to the study of Fischer-Tropsch catalysis and his current research work is largely in this area.

In addition to teaching and research, Bennett also served as acting department chairman on several occasions, but it was not his first love, and he was always happy to return to teaching and research. While teaching has its drawbacks for Bennett (especially tasks like grading exams), it still is one of the best parts of the job for him. "Teachers should teach people," he believes. "I suppose I enjoy the opportunity to make something clear. When I can describe something in such a way that it is comprehensible maybe I can remember the first time I looked at it, and I too, thought, that it was incomprehensible."

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Bennett teaches three undergraduate courses and one graduate course at UConn. One of these is a required 40-student section of the junior-year course in transfer operations. He also teaches advanced courses in transfer operations in the fall

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semester; one for seniors and one for graduate students. These tend to be more mathematically oriented. "The graduate courses are always pleasant because I usually get quite a few questions from the students and we have good discussions. But there is a lot to cover, so I wind up talking quite a bit," he says.

Bennett's teaching has had great influence around the world, since he has taught students on four continents—North and South America, Africa, and Europe. His first overseas teaching venture (at the University of Nancy in France) came in 1952, and reflected the influence of his continued love of the French language and culture that developed in his high-school and Yale days.

During his first visit to Nancy, Bennett helped form that university's chemical engineering department, according to one of his French colleagues, who added, "Having Prof. Bennett with us was extremely valuable. We benefited from his American experience and he gave us good advice on organizing courses and problems, on establishing laboratory experiments, as well as on the construction of buildings, and above all, the unit operations laboratory." During another visit to France in 1970-71, Bennett participated in research at Nancy on the design of catalytic reactors, and "made important contributions in the conceptual design of laboratory reactors," according to a colleague there, who also believes Bennett played a role in developing chemical engineering throughout France. He goes on to say, "Thanks to his perfect knowledge of the French language, Bennett has many times been consulted by academic authorities and even national ministries concerning important decisions in the domain of chemical engineering. Prof. Bennett's advice has always been heeded and followed." It is not surprising that the Bennett and Myers textbook is one of the basic books used by French chemical engineering students.

France also called to him during his 1977 sabbatical year, which he spent at the University of Lyon. At Lyon he worked as a laboratory researcher, read a great deal, and got to work with some of the leaders in the field of catalysis, many of whom were at Lyon. "I learned a lot there, and it helped me quite a bit, and influenced my career, too." Bennett reflects. He still maintains a cooperative research relationship with the University of Lyon, and exchanges transatlantic visits with some of its researchers.

Bennett's other extended foreign involvement was with a country in a quite different situation, Chile. He spent a period in 1964 at the University of Santa Maria in Valparaiso (under an Agency for International Development contract), returned there in 1972 as an Organization of American States lecturer, and last visited there in 1979. Thus he was in a position to watch that country's descent into turmoil, from the apparent normality observed on his first visit.

Bennett's teaching visit to Vienna, was shorter, only about a month in 1971. He also made two trips to Algeria, where he taught natural gas processing.

At home Bennett finds pleasure in many things other than his work. Besides being a "gourmet eater" (his son Johnathan is a professional chef), Bennett also enjoys classical music and art. He started playing piano at the age of eight and can play Scott Joplin rags, "ineptly" he claims. Otherwise, his tastes run more to Mozart, Beethoven, and Brahms. His interest in architecture and art now has professional guidance, since he married a UConn art professor and Egyptologist, Jean Keith, two years after his first wife, Elizabeth Jane Balch, died. Bennett and Keith were married August 24, 1979, on the anniversary of the eruption of Mt. Vesuvius, which buried the Roman city of Pompeii in 79 A.D., "a date quite suitable for us," Bennett notes. □

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engineering or returning to it. In its area of coverage, this book is more convenient to use and more comprehensive than the handbooks and it has the very great advantage of the worked-out example problems. The references, if not last minute, are at least solid and extensive. And I can also recommend the book for the faculty member called upon to teach design classes to have on his desk as a handy reference. The comprehensive problems given at the end of each chapter will also be useful to the faculty member.

In summary, this is a solid contribution to the chemical engineering literature, even if it does not suggest itself as a vital component of the undergraduate curriculum. I am certainly pleased to have a copy where I can reach for it. □