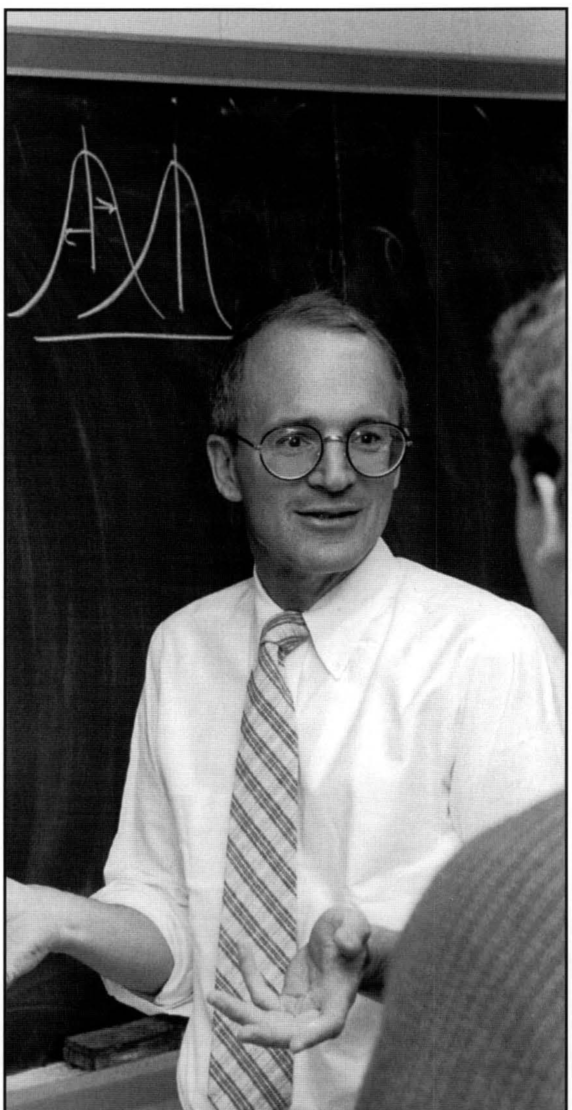
Minnesota's Ed Cussler



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Noontide at the University of Minnesota finds a lean, polychromatic, Lycra-clad figure emerging from Amundson Hall and loping off through the Twin Cities campus into the distance, where it is swallowed up—a lone, precursory coruscation in a sea of Midwestern mackintoshes. Is this, you wonder, an ambassador from some place better known for the vividity of its colors than for their sartorial harmony? No, the figure is that of IT Distinguished Professor Edward Cussler, perhaps in training for his next marathon or preparing for a *tour de* part of *France*, or maybe getting in shape to pull his oar to the head of the Charles River.

The "IT" in Ed's title denotes the Institute of Technology, the college that at Minnesota embraces all the natural sciences and engineering, and which gives the title "Institute of Technology Distinguished Professor" to only a small handful of its 500 faculty who are outstanding both in their teaching and their research. Indeed, Ed was already well known for both when Ted Davis persuaded him (and his colleague Fennell Evans) to translate from Carnegie-Mellon to Minnesota—one of the early successes of Davis' term of headship.

Ed's undergraduate degree was from Yale (with honors) in 1961, and his MS and PhD were taken at Wisconsin under Ed Lightfoot's mentorship. He then had three postdoctoral years: at Wisconsin, at Adelaide, South Australia, and in the Chemistry Department at Yale. He was appointed at Carnegie-Mellon in 1967 and had risen to full rank there by 1973—all this in only ten years after his first graduate degree!

Ed has always been known as an outstanding teacher, with animated delivery, apt illustration, and engaging originality. He won the Ryan

Undergraduate Teaching Award when he was at Carnegie-Mellon and has won a corresponding award no less than six times since coming to Minnesota. Of his first book, *Diffusion* (Cambridge University Press, 1984), one reviewer wrote, "This is an outstanding example of a text written by an expert in the field who cares as much about teaching the topic as he does about generating the research upon which progress in the understanding of mass transfer is based." Another supporter, having Ed's teaching in mind, observed, "He has throughout his career been something of an iconoclast, but with a basically positive and constructive attitude and a puckish sense of humor—three characteristics that are in short supply."

Ed has been in demand for the special-named lectures that are a feature of academia. He has given the Henskie Lectures at his alma mater, the Katz Lecture at Michigan, and the Danckwerts Lecture in London. The last of these is easily accessible, published under the title of "The Nature of Chemical Research" [*Chem. Eng. Sci.*, **53**(11), 1957 (1997)]. He won the Colburn Award of the AIChE in 1975 and ASEE's Lectureship Award in 1998. He maintains a vantage point from which he can see the broad trends of the profession through his chairmanship of the American Association of Engineering Societies and his associate editorship of the *AIChE Journal.*

Ed's research has been on diffusion and other modes of mass transfer. Though the analogies with heat transfer are illuminating, the time is long past (if indeed there ever was one) when mass-transfer problems could be approached as heat-transfer problems with a change of variable. Nowhere is that more obvious than in multicomponent diffusion, the subject of a monograph published in 1976 under that very title. He went on to publish a more general book, *Diffusion,* in 1984, of which a second edition was demanded in 1997, Meanwhile he collaborated with Wei-Shou Hu and Paul Belter on *Bioseparations,* a book published in 1988 by Wiley.

There can be no doubt of the importance of mass transfer to the understanding of chemical processes. It is often the rate-limiting step in a process and has to be considered both in the absence and the presence of reaction. New configurations that enhance desirable transfer, or that inhibit undesirable transfer, can be designed and novel situations analyzed—Ed has been active in all these aspects. For instance, in the so-called diffusion-solubility mechanism for a nonporous membrane, the solute dissolves in and diffuses across the membrane, being released on the other side to the adjacent medium. If the membrane is porous, the transport takes place only in the pores, but various mechanisms (*e.g.,* Knudsen diffusion or capillary condensation) may be involved. Ed has shown that a nonporous polyelectrolyte membrane can be 4000 times more permeable to ammonia than to nitrogen or hydrogen, a difference that is key to separations of agricultural chemicals.

Ed has also devised membranes for drying air and for direct methanol fuel cells. A barrier membrane, with impermeable, overlapping flakes hindering the diffusion can be responsible for a three-hundredfold reduction in flux for virtually any solute. In one dramatic series of experiments Ed verified that air could be selectively separated using a superconducting microporous membrane. This was a consequence of capillary condensation and not, as had previously been thought, of the Messiner effect.

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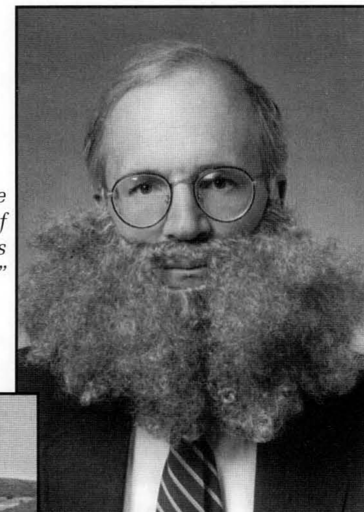
The greater part of Ed's research has been in membrane transport with reaction. This can selectively increase or decrease the transport; the former augers useful separations while the latter indicates the possibility of barrier packaging. The flux is increased by a reversible reaction between a solute and a mobile reagent to form a mobile complex that diffuses across the membrane and dissociates at the far side. The best-known example of this is the facilitation of oxygen transport in blood by hemoglobin. Working independently, Ed, Bill Ward of General Electric, and Norman Li of Exxon have formulated the basic ideas and have gotten some striking results. In one of Ed's systems, the flux of sodium (but *not* potassium) chloride can be enhanced ten-thousandfold by reaction. In other cases, solutes can be moved from a region of low to one of high concentration. In all cases it must be possible for all the solutes, reagents, and products involved to diffuse, a condition that negates certain claims.

Transport across a reactive membrane is decreased when a solute binds irreversibly to an immobile reagent. The steady-state flux is only slightly decreased in this case, but the time to reach steady state can lengthen a thousandfold or more, a phenomenon that should be useful in certain packaging situations. For example, an acid that may breach the film in ten seconds when there is no reaction may be retained for two hours when an immobilizing reactant is used, while for oxygen the breaching time can go from ten minutes to three years. Transport into reactive films can also change the location of reagents in unexpected ways, as when an acid dissolves calcium hydroxide or hydroxyapatite and reprecipitates the mineral in layers. Ed has shown that this is not a Liesegang Ring phenomenon, but comes about by the coupling of the linear transport and nonlinear reaction.

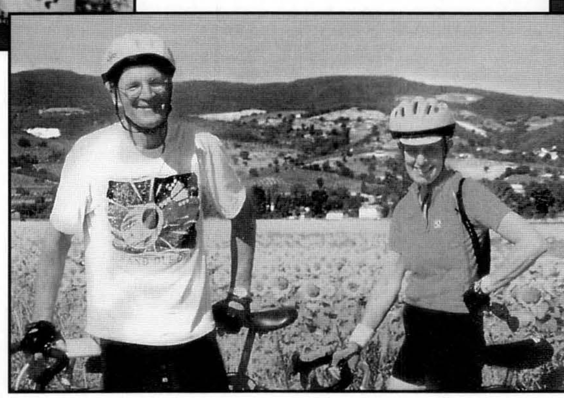
While Ed's work is fundamental research, his consulting keeps him ever mindful of possible applications and the design considerations that they engender. That experience is

▲ *A day on the Cam at Cambridge.*

◄ *Ed, with Alan Hatton and Rich Noble in Kyoto, 1990. Their shoes belie their effort to blend in.*



► *Ed trying to look like Arnie Fredrickson to gain the confidence of students because "everyone believes what Arnie says about thermo."*



▼ *Ed and Betsy taking a break on one of their bicycle tours of France.*

wide-ranging, and in addition to a long-term relationship with Pharmacia (*olim* Upjohn) and more casual contact with DuPont, Exxon, Dow, *et al.*, it included a year (1970-71) in England with Unilever. Though companies rarely expect much from visiting academics, Unilever was well satisfied with Ed's development of a fluoridized toothpaste that was sufficiently novel that it did not transgress existing patents. He also developed a dye of notable simplicity for coloring ladies' hair, its only drawback being that there was a complete loss of hair after three applications. There is no record of whether or not the patent rights were sold to a wig manufacturer.

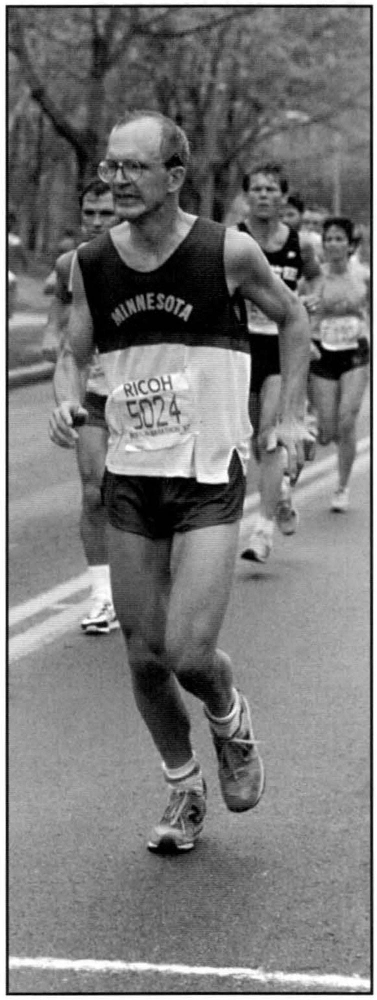
Ed first encountered the problem of texture perception when working with Unilever. He was able to predict and verify how texture would be perceived by tongue or fingers. Such psychophysical measurements might be of use in a rationale of consumer product marketing, but Ed confesses that he never figured out how this topic could be developed further. His is probably the only bibliography around that has such intriguing journal titles as *Cosmet.and Toil.* or *Perception & Psychophysics.*

More successful has been his development of membrane modules for absorption, extraction, and separation. These have the topology of the shell-and-tube heat exchanger, but the tubes are hollow fiber membranes, typically 300μm in diameter and offering virtually no resistance to mass transfer. Because these modules can have interfacial areas a hundredfold greater than the areas in common chemical separators, the modules can increase liquid extraction rates by a factor of three hundred and absorption rates of H_2S and HCN by factors of thirty. Ed has developed the design equations for various geometries and has shown that the plate height can be uncommonly sensitive to some perturbations of the fiber geometry. He has learned how to make the equipment more robust by using gel-filled pores, a valuable feature for racemic separations. He has eight patents on various uses to which these modules can be put. He even developed (but did not patent) an artificial gill that successfully allowed a beloved canine family member to stay quite comfortable under water, breathing oxygen like a fish.

It is easy to see that the tree of Ed Cussler's research is firmly rooted in fundamentals and ramifies into many branches. The temptation must be resisted to part the canopy here and there to reveal the branch of tooth decay, or of gallstone pathogenesis, or of the separation of protein for use in baby food, or of breaking the bonds of ice on Minnesota roads.

These topics are but a sampling from his bibliography of more than 180 papers and five books. His coauthors include the twelve Masters and thirty-six PhD students whom he has mentored and, occasionally, a colleague with whom he has shared a supervision or discussed a problem. Nor is it surprising that his books and papers are frequently cited. A 1971 paper in the *AIChE Journal* on "Membranes which Pump" has been referenced more than five hundred times by other authors.

His latest book, published in February by Cambridge University Press and coauthored with Geoff Moggridge, is titled *Chemical Products Design.* It is a product of the paradigm shift that has been taking place over the last decade in which Ed, both as an educator and as a professional, has played a leading role. The book is the immediate fruit of his sabbatical as Zeneca Fellow at the Shell Chemical Engineering Laboratory of Cambridge University (1999-2000).



The Boston Marathon, 1987.

Almost a decade before, a previous sabbatical (1991-2), spent at the other Cambridge, had been an opportunity for his concerns for the profession to gestate. Elected a Director of AIChE in 1989, he was Vice-President in 1993 and President the following year. In these positions, he came to feel that the key problem the profession was facing was the change from relatively few commodity processes with stable and fairly predictable markets to a product-oriented output for which demand would be changeable and price variable. As far as professional education is concerned, the intellectual and technological girth is much the same, but the orientation must be modified. With the change goes a change of expectation. No longer can chemical engineering graduates expect to spend their entire careers in one company, but must anticipate changing employers, probably more than once. European universities such as Cambridge, Grönigen, and Nancy have courses in product engineering, and they are increasingly common over here. Cussler and Moggridge will undoubtedly be a leading text in this millennial reorientation.

Ed is known far and wide for his teaching. He is conscious of the dramatic element in memorable teaching and will not disdain a hand puppet or a false beard if they will make a point stick. From time to time at Minnesota, we have surveyed a block of recent alumni, feeling that their undergraduate emotions recollected in the tranquility of their early experience beyond the department will give their opinions a distinctive degree of detachment. Certainly such a group is not slow to criticize, and almost everyone's teaching comes in for a brickbat or two—everyone except Ed. The high opinion of him that was formed as undergraduates remained uniformly favorable. One commented that Ed is "especially good at presenting industrially related material"; another said that she "never felt I had a firm understanding of the material (thermodynamics) until I had been through his course"; yet another claimed that "a visitor to one of Professor Cussler's thermodynamics lectures might find a hundred engineering students with their mouths gaping open and their tongues pointed upwards while the instructor ran around the room with an imaginary machete slicing make-believe sections through the students' extended tongues, which were serving as personal three-dimensional realizations of a vapor-liquid phase equilibrium diagram far more instructive than a chalkboard drawing or a textbook illustration alone." Small wonder that Ed has excellent rapport with students at all levels. It was he who had the idea of a departmental recognition ceremony on the afternoon of the college's auditorium-filling official graduation, thus giving a more personal touch that the students and their parents greatly appreciate.

Ed is the personification of Juvenal's *mens sana in corpore sano.* He began rowing at Yale as an undergraduate, and has rowed ever since when his athletic timetable, the proximity of the Cam, or the ice on the Mississippi permits. He was in a crew that twice finished Head of the Charles.

Ed and his wife, Betsy, manifest their mutual meetness, not only by both being excellent teachers (she of high school English), but also in their vacations. Not for them the sleek automobile tour or luxury cruise—rather it may be an arduous cycling trip in France or Spain. Last year they crossed Appenines from the Adriatic to the Mediterranean.

It was the day after he ran his first marathon that I (RA) first met Ed, and I have always regarded it as a great compliment that he dragged his aching body to my lecture and managed to stay awake and even to ask a question. Since then he has run twenty-five marathons (including the Boston Marathon seven times), and he still goes to seminars. Keep your eyes open and perchance you may catch a glimpse of his return—a melange of color slipping into his telephone-kiosk of an office, soon to emerge as the attentive and Distinguished Professor Edward (Clark Kent) Cussler, heading for the seminar room with his sandwiches and questions. ❐