A VISION OF EXCEPTIONAL TEACHING AMIDST EXCEPTIONAL RESEARCH

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NOTE

Composed for the William Resnick Memorial Issue of the I.I.Ch.E. Journal *(Vol. 22, April 1993; reprinted here, in part, with permission), this article not only does honor to Bill Resnick, who died suddenly in April 1992, but it also describes the vision and something of the reality of team teaching undergraduate chemical engineers at Minnesota since the 1960s. How that teaching has impacted undergraduate and graduate education, faculty development, research collaboration, and department ambience may be of interest to others in engineering education.*

Bill Resnick, an American chemical engineer who was the first department chairman at the Technion (Israel Institute of Technology, Haifa), spent the 1965-66 academic year as a Visiting Professor at Minnesota. He was drawn there by the vigorously fermenting brew of teaching-and-research in a department that was perceived more and more widely as taking the lead in chemical engineering. One of the attractions, he averred at the time, was the vision of team teaching, and the way the Minneapolis department's diverse band of professors was making the vision a reality.

That vision was an outgrowth of another—it had no clear beginnings, but a crucial stimulus was Neal Amundson's 1954-55 sabbatical in the new chemical engineering department at Cambridge University in England. There, the industry-seasoned Mr. Fox was melding an assortment of relatively young mechanical engineers, physical chemists, a surface chemist, and the odd engineer into a lively whole. (That was 'The Chief's' first and only sabbatical from the Minnesota department since 1949, the year he was named Acting Head at thirty-three years of age.) Amundson, himself a chemical engineer who had taken his PhD in mathematics, envisioned a similar broadening of the intellectual base and vitalizing teaching and research back home at Minnesota.

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Within a few years he attracted a half-dozen talented people to the faculty, most of them young, all of them inspired by the vision:

- A microbiologist, **Henry Tsuchiya** (1956): "...to reinforce the tradition of intimate cooperation with other disciplines (for strong connections with bacteriology, as well as with mathematics and chemistry, had existed since the 1920s)"
- A creative chemical engineer who had been in a mechanical engineering setting, **Bill Ranz** (1958)
- A unique hybrid of mathematician, physicist, engineer, and scholar whom Amundson had met deep in Imperial Chemical Industries in England, and with whom he later often teamed, **Gus (Rutherford) Aris** (1958)
- A non-Newtonian chemical engineer from the Bird school, who was soon to turn biochemical engineer and partner of Tsuchiya, **Arnie Fredrickson** (1959)
- A theoretical chemist of the Hirschfelder school and of the highest intellectual standards, who had been a postdoctoral fellow in The Netherlands, **John Dahler** (1959)
- A chemical engineer who had developed his fluid mechanical and interfacial proclivities working in the Shell Development Company, **Skip Scriven** (1959)

The later-comers helped attract each other, and the whole group fell into a resonance of shared goals, standards, and friendship that stimulated all of them, including the few older members of the department. That resonance was a strong attractant when the following openings were filled a few years later:

- A fire-eating chemical physicist, experimental and theoretical, who came from a postdoc in Belgium, **Ted Davis** (1963)

- ➢ A hybrid chemical/nuclear/biochemical engineer, liberally educated and Navy-seasoned, **Ken Keller** (1964)
- ➢ A physical organic chemist and chemical kineticist, a NIH Postdoctoral Fellow at Harvard, **Bob Carr** (1965)
- ➢ A physical chemist and surface physicist, a Research Associate at Chicago, **Lanny Schmidt** (1965)

Amundson was affectionately called the "Chief," and the rest of the band was occasionally referred to as his "Frontiersmen." All of them found irresistible the reality that had sprung from Amundson's original vision. But there was a further vision, one of unanticipatedly greater power in melting all the talent together and casting a coherent whole. That was the vision of teaching as a team.

A system of teaching the core undergraduate courses had long been in place—a system consisting of heavy problem-solving and relatively small problem-working sessions. In the section meetings, which alternated with lectures or labs, junior faculty and instructors had been working assigned problems and grilling students in a manner not uncommon in engineering instruction of that time. But apart from assigned problems, there was little coordination of section meetings with lectures.

Another significant feature was also in place: a policy (fostered by Amundson) that there would be no stand-up teaching in lectures or in recitations (or in laboratories, for that matter) by graduate students (save for the one or two advanced doctoral candidates appointed as instructurs). Consequently, each course was taught only once each year, with lectures three days a week and with the class split up into smaller problem sections for three more days each week (yes—the academic week at Minnesota was six days long at that time; Bill Resnick may have helped celebrate the end of that).

Bill Ranz recognized the potential for innovation in this system as well as the potential of the new faculty arriving with him. With Amundson egging him on, and with the new recruits and most of the older hands enthusiastically joining in, he took the lead in transforming what already existed into a team-teaching scheme. Its practice was some six years old when Resnick joined it in 1965.

What is the scheme? Can it be transplanted?

TEAM TEACHING OF UNDERGRADUATES

Chemical engineering classes of sixty to ninety students (fewer, long ago; more in most years now) are taught by teams of four faculty. In lecture courses, one professor is the lecturer and coordinator (responsible for lecturing, setting assigned problems and examinations, and coordinating the graduate teaching assistants who critique and grade student assignments). The lecturer also prepares recitation plans—outlines of lecture-related items, features of assigned and other problems to present and discuss with students (or to quiz them on) in section meetings. Each section, 15-25 strong, is headed up by a recitation leader—a professor, an instructor (a selected postdoctoral or advanced doctoral student), a visiting professor, or (in certain design, control, and laboratory courses) an adjunct professor.

The recitation leaders (and, if encouraged strongly enough, the graduate teaching assistants) attend the lectures. This is the heart of the innovation, and it violates a not-uncommon taboo against one professor sitting in on another professor's class. There are four faculty members at every lecture: one standing up front and three sitting in the back. If the lecturer is, say, a second-year assistant professor and the recitation leader is a grizzled full professor, the former is the teacher and the latter a student taking notes, jotting down ideas for recitation. Outside of class they discuss the lectures, recitations, problems, examinations, progress, and difficulties of students and grading. Everyone, including the teaching assistants, is actively involved.

With an audience as described above, a sloppy lecture is as rare as a May frost, or a January thaw, in Minnesota; a rare and embarrassing event not likely soon to be repeated. Standards are elevated—to the advantage of students. There is no uncertainty about classroom performance, nor is there any lack of constructive criticism and encouragement. Teaching is taken very seriously. Crafting lectures is arduous work, compounded by the demands of designing lesson plans and the rest. But the benefits for everyone concerned are fine.

The recitation leaders get the recitation plan a day in advance, and a couple of hours spent in preparation the night before is usually sufficient. Not infrequently they find themselves picking up the phone to straighten out some item with the other team members. An inexperienced newcomer may be given a late section in order to have the option of sitting in on some other section earlier the same day. In class the recitation leaders engage students in an intensive way not possible in lecture, and they come to know the students well. Year-in and year-out, most students have said that they especially appreciate the recitation and laboratory sections.

There is another central feature to this system: a faculty member has to have been a recitation leader in a course before she or he can lecture in that course. That means the lecturer has been immersed (if not submerged) in a complete course designed by a predecessor. He or she may then *re*design it, but with full knowledge of what has been done before. So course content tends to evolve and improve, again to the great benefit of the students.

And the last central feature: a faculty member has to leave a core course after lecturing in it for three successive years, or at most four. The first year is one of tailoring or revamping the course—and getting feedback; the second year is one of polishing the new version; the third year is likely to be one of coasting a bit. Then it's time to move on to another of the core courses. Thus, in time every professor diversifies as a lecturer into many of the core courses: stoichiometry and balances, fluid mechanics, thermodynamics, heat and mass transfer, separation processes, reaction engineering, control, and design.

The unit-operations-type laboratories are also team-taught, with sections of fifteen students divided into three-member groups. There is a professor present and in charge of each section, assisted by a graduate student, while one professor coordinates the whole course and chairs the weekly bag-lunch meeting of the entire team. In this way, almost every professor gains experience with the laboratory courses. As in the recitation section, the rotation time is likely to be just one or two years, not the longer cycle of those in charge of courses.

These features, taken together, result in faculty that know much of the curriculum intimately. If a professor is, for some reason, out of touch with the current version of a course, within a few years he or she can be back in very close touch. Everyone is well-informed and capable of integrating and evolving the curriculum over the long run, and for counseling undergraduate advisees term-by-term (actually quarter-by-quarter at Minnesota).

RESULTS OF TEAM TEACHING

For Undergraduate Students • Through the recitations and the similarly sectioned laboratories, students and faculty are put into closer contact. There is more effective transmission of what is taught that is *not* in any syllabus: the attitudes and standards, the patterns of thought about subject matter; the approaches to study, experimentation, and problem solving; the skills and styles of communicating—in short, the framework of the discipline and of the profession. As crucial as these factors are to engineering curricula, they are hard to define and even harder to measure, and so they go unexamined in evaluations. They are also hard for undergraduates to appreciate until later in their careers.

There are additional advantages for the students. Professors broaden and freshen by rotating through the core courses and the yearly reconstituted teaching teams. Heightened interest and enthusiasm of faculty and teaching assistants brings higher standards of teaching; the courses are well organized, with carefully selected coverage, quality lecturing, effective recitation and laboratory instruction, and automatic teaching and course evaluation. Courses evolve by a kind of natural selection at the hands of successive, overlapping teaching teams, some of which include adjunct professors from industry. Overcramming a course with material has to be guarded against, but a faculty that is collectively well-informed about the details of all the courses is enviably equipped to coordinate courses and integrate the curriculum. The capstone in chemical engineering is the senior course in process synthesis and design. Notwithstanding discussions that go back to Bill Resnick's stay and earlier, the potential for making that course the integrating kernel have barely been tapped.

For Graduate Students • As part of their education, graduate students assist in one ten-week course each year after the first year. Fuller involvement than mere grading is an excellent means of reviewing course material and rectifying deficiencies, an advantage widely recognized by PhD aspirants—and their advisors. A disadvantage of the team-teaching scheme is that opportunities for stand-up teaching are lost—though this is more than offset by the advantage to undergraduate students of faculty teaching of recitation and laboratory sections. But graduate students are able to begin as assistants on the floor of laboratory courses, in office-hour tutorials of lecture courses, and in mentoring undergraduate research participants. The most promising of those interested in academic careers can also qualify as instructors.

For Faculty • It is comparatively easy to take up a new course by attending lectures and preparing for and leading recitations—all the while learning or re-learning the material and reflecting on alternatives and improvements (not only in the course but also in its relation to other courses). New faculty, not having apprenticed as recitation leaders, cannot lecture in core courses during their first year when they are occupied with establishing research programs and, often, an elective course in their specialty. But through recitation and laboratory assignments they are exposed to role models, standards and values, and the camaraderie of shared teaching. Rotation through the courses affords opportunities to change over without undue effort, and thereby to master the entire core curriculum. A professor with primary responsibility for a postgraduate course in a given semester or quarter can retain a small active role in the undergraduate program by handling a recitation or laboratory section.

More significantly, professors who lack background in a particular area or, indeed, in the discipline of chemical engineering itself, gain an education through teaching. Bill Resnick witnessed a micro-biologist, physical chemists and chemical physicists, a physical organic chemist, a mathematician/physicist/engineer, and so on in various stages of this process. It is the way to weld into a lively whole a type of faculty particularly well suited to orient students toward a future in chemical engineering, where modern developments in chemistry, molecular biology, computer science, materials science, and related fields will continue to be applied. A by-product is a milieu in which instructors, postdoctoral fellows, and visiting professors from other fields (physical chemistry, applied mathematics, physics, mechanical engineering) have prepared for academic and industrial careers in chemical engineering.

A carry-over of the scheme is its permeation, scaled down, into some jointly taught elective courses and postgraduate courses—notably in the polymer and biochemical-biomedical engineering areas.

The most profound outcomes of all emerged over more than a decade. First was the subtle stimulation of research; then came fresh research collaborations by many of the faculty; then an exceptional atmosphere of research cooperation and collaboration. The combinations and recombinations of joint authors testify to this. So do graduate students, postdoctoral fellows, industrial fellows, and visiting and permanent faculty who have been attracted to it. The taproot of much of the exceptional research, and teaching of research, that ultimately emerged is clearly in the shared experiences, the special resonance, of undergraduate team teaching.

FINANCING

Team teaching by faculty entails greater costs than doing without recitations and relying on graduate-student teachers. The costs can be met by money from the institution to enlarge the faculty, or by subtle diversions of research funding to the same end, or by time from professors to discharge heavier responsibilities. Since Bill Resnick's stay, there has been a shift from the former to the last, with two results. One is that incremental costs are borne by professors, by sacrificing their recreational time and, all too often, their time with their families. The other is that the team-teaching scheme has been eroded by compromises, most noticeably through larger recitation sections, overcrowded laboratory sections, a greater number of graduate students appointed as Instructors, addition of senior faculty inexperienced in the scheme, and even temporary abandonment of recitation sections in a core course.

When institutional funding was less straitened, enrollments were lower, and commitment to the scheme was undiluted, the class-teaching load of regular faculty in the Minnesota department was structured as follows:

- *either* be in charge of a core course;
- *or* in charge of two of the following: a graduate course, an undergraduate elective course, a recitation section, a laboratory section;
- *or* just one of those, one quarter out of three each year.

Resnick's load was a bit heavier in 1965 when he taught the graduate thermodynamics course for two quarters in addition to participating in teaching teams all year. That was an era of graduate fellowships and traineeships, more funding for post-doctorates and visiting professorships, and other sources that could be drawn upon to support team teaching. The scene has, of course, changed. Institutional accounting of faculty time and allocation of available resources have made it much tougher to convince those in authority to invest in a single department's special programs in instructional effectiveness and faculty development.

TRANSPLANTATION

The question is why something approximating the whole scheme has not sprung up elsewhere. To be sure, many parts of it exist in many places, and they did so long before the total innovation got under way in Minnesota in the mid-1950s. It would appear that a number of circumstances are probably all necessary:

- *A sizeable group of young faculty, each inclined toward working together, teaching well, and broadening and deepening his or her mastery of the subjects in the curriculum.*
- *Effective leadership of the department and the core curriculum, coupled with a clear vision of the principles of the scheme.*
- *Older faculty with a compatible tradition, or at least with the self-confidence, flexibility, and talent to enter into a team-teaching scheme wholeheartedly.*
- *Some surplus of departmental resources and some commitment of faculty time to invest for the long term,.*

The biggest payoff of the team-teaching scheme comes over the long term. It brings unique opportunities to strengthen teaching and curriculum, followed by the integration of teaching and research, and then research itself, especially cooperative and collaborative research within the department—that is, to strengthen ultimately the whole enterprise.

A great impediment for most institutions seems to be a taboo against one professor sitting in on another professor's class. Another seems to be a reflexively negative response of entrenched faculty to the prospect of preparing new courses, and still another impediment is university accounting of apparent costs—headcount-based measures (*i.e.,* apparent cost per student), lack of measures of benefits and effectiveness, and the common practice of using obtuse comparisons with other departments as the basis for budget decisions.

CLOSING

At the 1981 Annual Meeting of the American Institute of Chemical Engineers, I described the fruitful innovation of team teaching. Since that event I wanted to ask Bill, the consummate professor and indefatigable traveler, for his answer to the transplantation question. But we always met on short notice or in busy situations: a conference he organized in Arad, a one-day whirlwind tour together of much of Israel, a dinner given by chemical engineers in Santa Fe (Argentina), a hallway of an AIChE meeting, a review of the department at Ben Gurion University. The last was several December days in 1988 spent together focusing intensely on the inseparable teaching-and-research of an admirably dedicated faculty in our discipline. It reflected beautifully the activities and discussions of the 1965-66 academic year in Minneapolis. Bill is a friend and kindred spirit. How I would like the pleasure of catching up with him again, as usual, in some unpredictable place! ❐