Educación Química, 15(1), 40-42 (2004)

TEACHING ENGINEERING AT A RESEARCH UNIVERSITY: PROBLEMS AND POSSIBILITIES

Richard M. Felder
Hoechst Celanese Professor Emeritus of Chemical Engineering
North Carolina State University

I have taught chemical engineering for the past 34 years. I entered the profession in 1969 with the standard training in pedagogy that most professors receive—none—and by default proceeded to do unto my students as had been done unto me. I prepared my lecture notes and transcribed them onto the board for the students to copy, sometimes asked questions, occasionally got answers from a few of the more fearless students, and gave tests on which the class average hovered around the low sixties with some grades below 20.

After about a decade of this routine, it began to dawn on me that things were not going exactly the way I had in mind. As I stood at the board lecturing, I found myself increasingly aware of the glazed eyes, nodding heads, and people reading newspapers and talking to their neighbors. Also, I had always viewed low grades on tests as the natural order of things in engineering, but now I started to wonder whether the responsibility for the terrible performance of some my students might be at least partially mine.

It is not that I was a careless or unconcerned teacher. I spent a lot of time preparing lecture notes and delivered them in a clear and well-organized manner, consistently got high ratings from my students, and even won several teaching awards. But the true measure of teaching effectiveness is the quality of student learning, and the more I thought about those low grades the more I had to acknowledge that my teaching was clearly not effective. I was doing all the intellectual work of organizing and illustrating the course concepts, which the students really appreciated, but doing all that is precisely what leads to real understanding. The result was that *I* was learning the course material extremely well, but they were not. At that point I began for the first time in my career to think seriously about what I was doing and whether there might be better ways to do it.

Shifting responsibility to the students

In the years since then I have come to realize that nobody ever learned anything nontrivial by having someone else tell it to them. For students to learn in a meaningful manner, they must be actively engaged in the learning process.

Active engagement is what I try to achieve now in every class I teach. Instead of spending all my time writing detailed derivations and problem solutions on the board for the students to copy, I get

them—sometimes working individually, sometimes in small groups—to confront problems themselves during class. Some problems are straightforward, with one correct solution, and others have several possible solutions that the students must first think of and then evaluate critically to determine the best one. Whether or not they get the right answer is not so important; what matters is that they are actively involved in the search for it. They often succeed, and when they don't and I provide the solution, they are ready to hear it in a way that would not be possible in a traditional lecture class.

My homework assignments and tests are also different now. They used to consist entirely of formula substitutions (given this and this, calculate that) and derivations. I now also assign some problem formulation exercises and some "thought" problems ["*Explain in terms a high school student could understand the concept of vapor pressure.*" "*Why do you feel comfortable in 70^{O}F air, cold in 70^{O}F water, and even colder when you come out of the water?*" "*Why does it take longer to cook chili at a ski resort than at the beach?*" "*Which will keep you warmer—a loosely fitting, loosely knit sweater or a tightly fitting, tightly knit sweater? Why?*"] By design, some of these problems involve material in readings that I have not explicitly lectured on in class.

Perhaps the biggest change in how I teach has been my adoption of cooperative learning. Formerly all homework was done individually and test and course grades were curved, which meant that students were discouraged from helping each other and thereby possibly lowering their own grades. Now most of the homework is done in teams, with a variety of structures in place to assure individual accountability for all the material covered in the assignment. Course grades are assigned on an absolute scale, so that in principle everyone can get A's (or F's) and students have every incentive to help one another on homework and test preparation.

Since I started using these methods, both test and course grades have been significantly higher than they were before, even though I now give harder tests. My office hours have also changed considerably. Before, students would come by to ask how to do a particular problem in the book, I would show them, and they would leave. I rarely get that kind of question now—someone in the group can usually find a way over the hurdles in most problems. Instead, I get teams of students locked in mortal combat over one of those thought problems, which makes for sessions that are more interesting for me and much more instructive for them.

As well as this teaching approach works, however, not all students like it. Some do not want to work in teams and resent the fact that I make them do it, and most of them hate being held responsible for material I have not explicitly covered in lectures. They always counted on their teachers to tell them everything they needed to know for the exam, and a few complain bitterly about having to dig things out for themselves.

I welcome these students to their future life. When they go out into the world to be engineers, there will be no teachers, no lectures, no example problems with worked-out solutions. My goal is for them to learn now what they will need to know then—how to use the library, the Internet, their colleagues, and

their intellect and common sense to solve real problems. Sooner or later most of them get it, but several resist to the end. I can live with their resistance; the improved learning I can clearly see more than compensates for the occasional hostility.

Professors are made, not born

Cooperative learning, problem-based learning, assignment of open-ended multidisciplinary problems, problem-formulation exercises, absolute grading criteria, and most of the other teaching strategies I now use are not inventions of mine. Educational psychologists have known about them for years, and research has consistently shown that they work better than the traditional approach based on formal lecturing and assignment of only well-defined single-discipline single-answer problems. So why don't all professors use these methods? Because most professors don't know about them.

College teaching may be the only skilled profession for which systematic training is neither required nor provided—pizza delivery jobs come with more instruction. On most campuses you join a faculty and they tell you that you'll be teaching CHE 205 this semester, and off you go to teach it without so much as five minutes on how one does that. In the absence of a better model, most of us do what I did and teach the way we were taught, and since our professors (who also never got any training) lectured and wrote things on the board for us to copy, that's exactly what we do.

The fact is that people are not born knowing how to teach, any more than they are born knowing how to repair an engine, remove an appendix, or design a bridge. Teaching is a skilled craft. Granted, anyone—trained or not—can get up in front of a group of students and present information, but few without suitable training or experience know how to motivate, excite, and inspire students to learn, or construct tests that are both rigorous and fair, or deal appropriately with the range of academic deficiencies and emotional problems many students bring to class with them, or promote the attitudes and abilities that enable individuals to become lifelong learners. Fortunately, like the skills associated with other crafts, teaching skills can be learned and developed through practice and feedback. Some universities have begun to acknowledge this fact and offer voluntary teaching seminars, but training in pedagogy is still not regarded as an essential part of faculty development and few faculty members are inclined to study it on their own.

Internal satisfaction goes only so far

One reason that more faculty members do not bother to learn alternative teaching methods is that they have few incentives to do so. Quite the contrary. For the last 50 years or so, the reward system at most universities has tilted overwhelmingly toward research. Professors who do good research—write the proposals and get them funded, present at the conferences, publish the papers—get tenure, promotions, good raises, and all-expense-paid trips to exotic places. Nothing comparable exists on the

teaching side. Most professors who put in all the time and energy it takes to do first-class teaching get little back but self-satisfaction and perhaps a teaching award or two—and those whose success at teaching comes at the expense of their research usually find themselves looking for new jobs.

Although some professors manage to do both outstanding research and outstanding teaching (often sacrificing their health or personal relationships in the process), there are not nearly enough of them to populate our faculties. Doing world-class research is essentially a full-time job. So is doing outstanding teaching—not just going in and giving good lectures but developing new and innovative educational methods and using them. I believe that a substantial majority of faculty members are concerned about students and would really like to be great teachers, but given the present academic reward system and the limited number of hours in a day, most settle for being adequate.

What is the solution?

Research and graduate student training are vitally important university missions. So is undergraduate education. Requiring all professors to make research their top priority if they want to move up the academic career ladder hurts the quality of undergraduate education. It also doesn't do much for the overall quality of research, much of which is motivated more by the publish-or-perish syndrome than by intellectual curiosity or the hope of improving society. The question is, how might we improve teaching quality without sacrificing research quality?

There isn't one simple answer, but I can suggest some possibilities.

- Institute a campus-wide teaching assessment and evaluation program based on the use of the teaching portfolio, which provides a broad spectrum of assessment tools in addition to the usual course-end student evaluations.

- Provide for faculty development on a continuing basis, both in workshops and through individual consulting for professors whose evaluations reveal inadequate teaching quality.

- Recognize educational scholarship (developing and writing about improved teaching methods, writing undergraduate textbooks and instructional software, incorporating technology into the classroom, carrying out distance learning, securing grants for educational research, participating in educational conferences, publishing in education-related journals, etc.) as a faculty pursuit no less valid and valuable than disciplinary research.

- Treat research and teaching equally when making decisions on faculty tenure, promotion, and raises. If outstanding research is required of all faculty members, make outstanding teaching a concurrent requirement. Better yet, if outstanding scholarship and adequate teaching is sufficient for advancement (as is the case almost everywhere), then make it equally possible to advance on the basis of outstanding teaching and adequate scholarship, including educational scholarship.

- Make sure every academic department and program has at least some outstanding teacher/scholars who can serve as educational consultants to their more research-oriented colleagues and as mentors to graduate students planning on pursuing academic careers.

Doing all that would take some commitment of resources, considerable effort, and a major attitude adjustment on the part of both administrators and professors. The unquestionable benefits to the students are evident, however, and the ultimate beneficiaries would be the eventual employers of the students and society in general. I believe it is worth trying.

Bibliography

Detailed discussions of the ideas presented in this paper can be found in several of Richard Felder's publications, including the following ones:

R.M. Felder and R. Brent, "Designing and Teaching Courses to Satisfy the ABET Engineering Criteria.," *J. Engr. Education, 92*(1), 7–25 (2003).
<*http://www.ncsu.edu/felder-public/Papers/ABET_Paper_(JEE).pdf*>.

R.M. Felder and R. Brent, "Effective Strategies for Cooperative Learning," *J. Cooperation & Collaboration in College Teaching, 10*(2), 69-75 (2001).
<*http://www.ncsu.edu/felder-public/Papers/CLStrategies(JCCCT).pdf*>.

R.M. Felder, D.R. Woods, J.E. Stice, and A. Rugarcia, "The Future of Engineering Education. II. Teaching Methods that Work, *Chem. Engr. Education, 34*(1), 26-39 (2000).
<*http://www.ncsu.edu/felder-public/Papers/Quartet2.pdf*>.

D.R. Woods, R.M. Felder, A. Rugarcia, and J.E. Stice, "The Future of Engineering Education. III. Developing Critical Skills," *Chem. Engr. Education, 34*(2), 108-117 (2000).
<*http://www.ncsu.edu/felder-public/Papers/Quartet3.pdf*>.

J.E. Stice, R.M. Felder, D.R. Woods, and A. Rugarcia, "The Future of Engineering Education. IV. Learning How to Teach, "*Chem. Engr. Education, 34*(2), 118-127 (2000).
<*http://www.ncsu.edu/felder-public/Papers/Quartet4.pdf*>.

R.M. Felder, J.E. Stice, and A. Rugarcia, , "The Future of Engineering Education. VI. Making Reform Happen., "Chem. Engr. Education, 34(3),208-215(2000).
<*http://www.ncsu.edu/felder-public/Papers/Quartet6.pdf*>.

R.M. Felder, "Active, Inductive, Cooperative Learning: An Instructional Model for Chemistry?" *J. Chem. Education, 73*(9), 832-836 (1996).

R.M. Felder and R. Brent, "Navigating the Bumpy Road to Student-Centered Instruction," *College Teaching, 44*(2), 43-47 (1996). <*http://www.ncsu.edu/felder-public/Papers/Resist.html*>.

R.M. Felder, "The Myth of the Superhuman Professor," *J. Engr. Education, 82*(2), 105-110 (1994). Translated into Spanish and published as "El Mito del Profesor Superhumano," *Educación Química, 5*(2), 82-88 (1994). <*http://www.ncsu.edu/felder-public/Papers/Mythpap.html*>.

Dr. Richard M. Felder is Hoechst Celanese Professor Emeritus of Chemical Engineering at North Carolina State University. He is a coauthor of *Elementary Principles of Chemical Processes* (3rd Edition, John Wiley & Sons, 2000), which is used as the introductory chemical engineering textbook by 90% of all chemical engineering departments in the United States and many others elsewhere. He has authored or coauthored over 200 papers on chemical process engineering and engineering education and has presented seminars, workshops, and short courses in both categories to industrial and research institutions and universities throughout the United States and abroad. He has won a number of awards for his research, teaching, and publications, including the Chemical Manufacturers Association National Catalyst Award, the ASEE Chester Carlson Award for Innovation in Engineering Education, the AIChE Warren K. Lewis Award, and the ASEE Chemical Engineering Division Lifetime Achievement Award for Pedagogical Scholarship. Many of Dr. Felder's papers on engineering education can be found on his Web site: <*http://www.ncsu.edu/effective_teaching*>.