2006-369: THE CHANGING CHE CURRICULUM – HOW MUCH CHANGE IS APPROPRIATE?

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Introduction

The changing chemical engineering curriculum is a popular topic these days. Most agree that changes are needed to keep up with evolution of the discipline and to continue to attract high-quality students. However, there appears to be disagreement on the speed and scope of these changes. Some prefer a revolutionary approach[1], while others prefer an evolutionary approach.[2] This paper presents the views of one academic who started studying chemical engineering in the slide-rule era.

To emphasize the need for curriculum change, several of the excellent papers on the knowledge structure of chemical engineering can be examined.[3,4] These papers were published in 1993, and there was no specific mention of life sciences, nanotechnology, or molecular phenomena (even in the thermodynamics class). The knowledge structure of chemical engineering has changed significantly over the history of the discipline. This change occurred at different rates at different times, and historically, the undergraduate curriculum has changed concurrently. With the exception of incorporation of advances in computational technology, the chemical engineering curriculum has more or less remained stagnant for a generation. Therefore changes are needed. However, it may not be possible to add new content without removing some existing content and still maintain a four-year degree. The question being debated is what should be added and what can be removed.

The U.S. chemical industry has not experienced much growth in several decades; in fact, it is probably contracting as more capacity is transferred overseas. Employment opportunities for chemical engineers are moving from jobs involving continuous, organic, chemical processes at traditional chemical companies to batch production and product innovation at consumer and life-science oriented companies.[5,6] Therefore, to remain relevant, most academics agree that biology should now be included as an enabling science, along with chemistry and physics. But what other changes are needed?

The starting point for any curriculum change is virtually the same in every department. An examination of the chemical engineering curriculum shows very little difference between departments. The unified curriculum in chemical engineering, which has historically set chemical engineering apart from other engineering disciplines, may now be a weakness rather than a strength, which would suggest that it is time for a paradigm shift. Some will say that we have not responded quickly enough to the changing profession, and this may be true. Others will blame ABET. However, the new criteria allow far more flexibility, but departments have been slow to make changes. Still others will blame the university reward system, which does nothing to encourage senior faculty members to devote time to significant updates of classes they have taught for years or to encourage anyone to write books that embrace the changing face of chemical engineering.

A case has been made for a major curriculum revolution in chemical engineering.[1] The argument will be made here that while such a revolution may be appropriate for some, it is not appropriate for all chemical engineering departments.

The Case for Slow Change

The challenge to remain relevant must be tempered by a reality check. What does it mean to remain relevant? It does not necessarily mean to jump on every administrator-favored bandwagon. Chemical engineering education is in an assessment mode. It is our responsibility to produce students with knowledge and skills appropriate to the needs of our constituencies. Students and parents are constituencies, and their primary need is for the skills and knowledge that make the graduate employable or prepared for graduate or professional school. The companies that employ our students are another constituency. How many chemical engineering departments can correctly claim that the companies that employ their graduates would continue to do so if their graduates were well-schooled in molecular dynamics calculations and ignorant about distillation and heat exchangers? *Highly Selective Institute of Technology*, which trains a significant portion of its students for graduate/professional school, may be able to make this claim. However, *State University*, which trains most of its students to work for the local/regional refineries or traditional chemical plants probably cannot make this claim. It appears to be an often-ignored fact that there are a large number of traditional chemical plants and refineries in the U.S. that still require traditionally trained chemical engineers. Of the 150 or so chemical engineering departments in the U.S., more are in the latter (SU) category than in the former (HSIT) category. There is, of course, a middle ground of larger, state universities that are in regions with "high-tech" industries.

Therefore, I have already identified three possible types of chemical engineering departments. These are obviously three points on a continuum. One has constituencies who want students trained in the engineering problem-solving methodology and in the latest advances in the enabling sciences. Another has constituencies that want students with the skills to work in the local "high-tech" industry. Yet, another has constituencies that want students with skills appropriate to the traditional chemical industry. I believe that we can look to the electrical engineering community for a parallel situation that we may not wish to repeat. In the generation of our most senior faculty members, most electrical engineering graduates entered the power systems industry. The current generation is more interested in computers, robotics, VLSI, etc. Suppose that history repeats itself in chemical engineering? Suppose that our profession evolves so that the "sexy" jobs are only in nanotechnology, biotechnology, etc. Who will staff our existing chemical plants? It will probably be those who cannot get positions in the "sexy" areas, very likely those in the lower half of the class. Chemical engineering cannot afford this type of bifurcation. We want to avoid having graduates running chemical plants, with all of their inherent dangers, because they could not find a job elsewhere. The chemical industry has a shaky enough reputation. People are afraid of chemicals, some viewing all chemical-producing companies as evil. Can we afford not to have some of our best and brightest in charge of chemical processes full of toxic, flammable, and explosive materials?

How to Proceed

My suggestion for how the profession should proceed will be loathed by most administrators. Despite rampant budget cuts, most universities want to do "everything." All pay lip service to teaching, want "world-class" research and its concomitant funding, see visions of technology transfer leading to the next Gatorade™ or Coumarin™/Warfarin™, and state schools want to satisfy the legislature's belief that the university can solve the state's economic woes.

However, I believe that individual universities cannot do everything. Small chemical engineering departments with 5-10 faculty members and 20-30 graduates cannot always afford to teach multiple elective classes in nanotechnology, biotechnology, and fuel cell technology to 5-10 students per class and still have time to devote to research; although, a suggestion for solving this problem is presented later. Most departments should acknowledge that they must find a niche and emphasize it. An example of this is at the graduate level, where chemical engineering at the University of Maryland, Baltimore campus is all bioengineering related. I believe that we must now choose this path at the undergraduate level. Chemical engineering departments must tailor their curricula to the needs of their constituencies. It will be assumed, for the sake of argument, that most students seek employment in the same region of the country where they attend school (probably more true for state schools). Therefore, since West Virginia and the surrounding states contain numerous traditional chemical plants, steel mills, very few pharmaceutical companies, and virtually zero microelectronics companies, the local companies (duPont, Dow, for example) want traditionally trained chemical engineers. In a region containing numerous microelectronics companies but very little traditional chemical industry (perhaps Arizona), programs should provide training appropriate to the needs of these companies. In a large state (Texas, for example) with a large program and a more diverse set of chemical engineering employers, departments can offer training appropriate to different industries.

I believe that the curriculum of the future will focus on one or two areas (process engineering, biotechnology, nanotechnology, energy, for example) and only provide an introduction to other areas. Several model curricula are suggested. Table 1 contains a suggested traditional chemical engineering curriculum. This is what many programs do now. The modern areas are not ignored, but are offered as electives. It is also suggested that problems from modern applications of chemical engineering principles be incorporated in traditionally named classes. It is observed that several sets of companion materials have been published over the years for this purpose, but they have not all been widely used.[7-9] So, it is not clear how successful this suggestion would be. For a small department, a new class entitled "modern chemical engineering" might be a method for incorporating an introduction to areas like nanotechnology, interfacial phenomena, microelectronics processing, etc., into a single elective. This could also be a required class to ensure that the traditionally trained chemical engineer has exposure to the modern aspects. Design projects outside the scope of continuous, petrochemical processes can also be incorporated.[10,11]

Table 2 shows my interpretation of the revolutionary curriculum recently suggested in a series of workshops.[1] It is difficult to look at Tables 1 and 2 and believe that these are for curricula with the same name!

Clearly, there must be a happy medium between the curricula listed in Tables 1 and 2. Two possibilities are in Tables 3 and 4. In Table 3, a curriculum that emphasizes modern areas of chemical engineering is shown. Table 4 is an attempt to make the curriculum of Table 2 more acceptable to traditionally trained chemical engineers. The elective(s) in unit operations could be

Table 1: Suggested Traditional Chemical Engineering Curriculum

Required Subjects	**Basic Sciences**
basic skills/freshman class	math
material and energy balances	chemistry
thermodynamics	physics
fluid mechanics	biology
heat transfer	
mass transfer/separations	**Possible Electives**
transport phenomena[§]	safety
reaction engineering	biochemical engineering
control	materials/polymers
unit operations laboratory class(es)	microelectronics processing
design	modern chemical engineering

[§]if not integrated into other classes

Table 2: Possible Molecular/Multi-scale Chemical Engineering Curriculum

Required Subjects	**Basic Sciences**
molecular thermodynamics	math
molecular-based reaction kinetics	chemistry
molecular biology	physics
interfacial phenomena	biology
interfaces and assemblies	materials
reaction engineering	
reactions at different length scales	**Other Classes**
design at different length scales	business/management
math modeling of systems	
modeling of molecular systems	
systems design	
related laboratories*	

*related to molecular engineering, not traditional unit operations

Table 3: Possible Curriculum in Modern Chemical Engineering

Required Subjects	**Basic Sciences**
basic skills/freshman class	math
material and energy balances	chemistry
thermodynamics	physics
molecular thermodynamics	biology
transport with unit ops	
reaction engineering	**Possible Electives**
materials	advanced traditional unit operations
biochemical engineering	process design
polymers	
modeling/control	
product design	
related laboratories[†]	

[†]related to curriculum emphasis

Table 4: Possible Curriculum in Molecular-based Chemical Engineering

<table>
<tr><td rowspan="2">Required Subjects
basic skills/freshman class
material and energy balances with emphasis on modeling and unsteady state behavior
molecular thermodynamics
biomolecular engineering
continuum transport phenomena
reaction kinetics and engineering
materials and/or polymers
biochemical engineering
interfacial phenomena
nanotechnology
systems design
related laboratories‡</td><td>Basic Sciences
math
chemistry
physics
biology</td></tr>
<tr><td>Possible Electives
traditional unit operations
process design
product design</td></tr>
</table>

‡related to curriculum emphasis

a requirement, which would ensure some training in traditional chemical engineering. Many other variations on this theme are possible by changing the non-traditional, required subjects.

These model curricula are meant to be caricatures of possible future chemical engineering curricula. The point is that a chemical engineering curriculum can be tailored to specific needs, but a curriculum that incorporates extensive training in both traditional and modern chemical engineering probably can not be completed in four years. By taking advantage of the flexibility of the current accreditation criteria, any of these curricula would pass accreditation as long as there were an assessment plan in place to show that the curriculum responds to the needs of the constituencies and produces graduates meeting the stated educational objectives and program outcomes.

Can all of these curricula be called chemical engineering? Why not? We always extol the flexibility of chemical engineers. An analogy to civil engineering may be appropriate. The civil engineering program criteria require competency in a minimum of four recognized major civil engineering areas.[12] There are more than four such areas, so the expertise of civil engineering graduates varies. Perhaps the chemical engineering profession needs to recognize that it can produce graduates with expertise in different sub-areas of the rapidly expanding profession.

Finally, there is a possible method to address the problem facing smaller chemical engineering departments wanting to offer training in a variety of areas. This would require a paradigm shift in chemical engineering education. The premise is that most chemical engineering programs have neither the staffing nor the expertise to offer depth in a variety of modern chemical engineering areas. A potentially new model for educating students in these areas is that multi-course modules in modern areas would be prepared by different departments based on their specific areas of expertise, and that these modules would be delivered to cooperating departments via the Web. Departments could group together based on complementary expertise to ensure that a variety of modules were available to students in all of the departments. (I can just imagine administrators choking on this and asking why an individual department does not have all of the expertise needed in all areas while simultaneously cutting the budget!) In the future, it is possible that AIChE or CACHE would ultimately coordinate development of and access to these instructional materials.

Conclusion

It is suggested that departments work with their constituencies to determine the appropriate curricular content. Departments should avoid the "keeping up with the Joneses" attitude. One department's curriculum may ultimately differ from another's by virtue of geographical location. Some may have traditional chemical engineering curricula, others may have molecular-based curricula, and others may have something in between. As the scope of chemical engineering expands, we cannot train students in all areas without resorting to superficiality. We should pick and choose our curriculum content and educate our students in depth in our appropriately chosen topics.

Bibliography

1. "Frontiers in Chemical Engineering Education," CCR/NSF Workshops, see information at http://web.mit.edu/che-curriculum.
2. Kauffman D., R. Busch, A. Datye, and T. Ward, "The Minimum Core for Chemical Engineering: How Much Bathwater Can We Throw Out?" ASEE 2005 Conference Proceedings, Session 1413.
3. Felder, R. M., "Knowledge Structure of the Stoichiometry Course," *Chem Engr Educ*, 27 (2), 92-95, 1993.
4. O'Connell, J. P., "Thermodynamics. A Structure for Teaching and Learning about Much of Reality," *Chem Engr Educ*, 27 (2), 96-101, 1993.
5. Cussler, E. L. and J. Wei, *AIChE-J*, 49 (5), 1072-1075, 2003.
6. Cussler, E. L., *Chem Engr Educ*, 33 (1), 12-17, 1999.
7. Shuler, M. L., *Chemical Engineering Problems in Biotechnology*, AIChE, New York, 1989.
8. Center for Chemical Process Safety, *Safety, Health, and Loss Prevention in Chemical Processes*, AIChE (CCPS), New York, 1990. (plus additional electronic materials distributed by CCPS)
9. Allen D. T. and D. R. Shonnard, *Green Engineering. Environmentally Conscious Design of Chemical Processes*, Prentice Hall PTR, Upper Saddle River, NJ, 2002.
10. Shaeiwitz, J. A. and R. Turton, "Design of a Transdermal Delivery System: A Case Study in Product Design and Multi-scale Design," ASEE 2004 Conference Proceedings, Session 3413.
11. Shaeiwitz, J. A. and R. Turton, "Food Processing: Another Case Study in Biologically Related Product and Multi-scale Design," ASEE 2005 Conference Proceedings, Session 3113.
12. ABET, "Criteria for Accrediting Engineering Programs," (2005-2006 cycle), ABET, Inc., Baltimore, MD, 2004.