THE FUTURE OF CHEMICAL ENGINEERING – AN EDUCATIONAL PERSPECTIVE

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1. Looking at the Future of Chemical Engineering. From the time they step across the threshold of their first stoichiometry class, chemical engineers are looking to the future of their profession. Once seated in that earliest classroom, they are continually preparing for the future – throughout their entire careers. The curriculum, set by their undergraduate professors, not only must provide the traditional concepts and techniques for their practice, but also must convey their teachers' best insights into the new concepts and techniques that they will need over the first ten years of their careers, as well as how to acquire what they will need beyond that period. When one reviews the first 100 years of the Chemical Engineering Profession it is clear that the description of a Chemical Engineer continues to evolve and change – and practitioners must be life long learners.

From time-to-time industry, government and academe gather to project the future of chemical engineering to assist educators in setting their curricula by defining and characterizing where the profession is heading. A recent set of gatherings, commissioned by the Council for Chemical Research (CCR) and funded by the National Science Foundation (NSF), was organized by the Massachusetts Institute of Technology. In addition to examining the future of the profession, it called for a major adjustment to the strategy of the curriculum. Two parallel sets of activities are working toward transformation of the curriculum. Several universities have given particular attention to embedding new and developing computerized computational techniques into the curriculum; and the NSF has contracted several universities, including the University of Pittsburgh, to create new frameworks that could be used for such new curricular material, as well as for the standard subjects.

On a continuing basis industry and academe work together under the umbrella of ABET, Inc. (originally known as the Accreditation Board for Engineering and Technology) to set criteria for the various engineering curricula and verify proper alignment with the criteria by the engineering colleges and schools in the United States. Six years ago ABET thoroughly revised its approach to setting criteria and established the EC2000 accreditation process that allows the new curricular strategy, defined at MIT, and the new framework, developed at Pittsburgh, to be instituted. And, specific to the emerging concepts and practices in bio-related aspects of a number of engineering disciplines, ABET continues to revise its criteria for biological engineering, bioengineering, biomedical engineering and biochemical/biomolecular engineering, showing that bio-related engineering transcends the traditional disciplines and is truly multidisciplinary.

When industry, government and academe have agreed on the concepts and techniques that are needed in the current and future practice of engineering, and ABET has established clear curricular criteria, the engineering licensing boards have the parameters they need to establish specifications and write items for examinations that verify the minimum competency of those seeking to publicly offer their engineering services in these new areas throughout their careers. Currently the National Council of Examiners for Engineering and Surveying offers licensing exams on behalf of US State and Territory jurisdictions in many disciplines including Chemical Engineering. Importantly AIChE, together with a number of other professional societies that represent engineers working with biological systems, are just beginning the process of establishing a Bio-related Engineering P.E. License with NCEES.

Technical societies and universities provide valuable assistance to all engineers by defining and offering a variety of continuing professional development offerings, including continuing education courses describing emerging technologies and techniques. AIChE's Continuing Education Program, now known as the Education Services Program, began in 1965 and has offered hundreds of courses to thousands of chemical engineers over the decades. Currently its courses are offered through the Continuing Education Institute of the American Society of Mechanical Engineers. The AIChE Education Services Committee has the responsibility to foster the development of new courses for the Education Services Program. It also is assisting in developing new internet delivery approaches that promise to take on greater significance over the coming years.

Chemical engineering is being transformed by globalization of the world economy. The National Academy of Engineering[i] issued the following challenge to engineering schools to:

> "*establish* and publicize a *capability* for providing information on international engineering programs, and *for promoting* an *awareness of the international nature of technology*." And
> "expand *opportunities for engineering students to study abroad* through the pairing of U.S. schools with comparable schools abroad, and also should encourage the development of *cooperative efforts between engineering schools and other campus units* expert in international economic and cultural affairs."

Currently the effects of globalization are resulting in the off shoring of U.S. engineering jobs to overseas competition. In a recent report by the McKinsey Global Institute[ii], the offshoring potential of several professions related to eight industry sectors was studied. Engineering was identified as the most "amenable" to offshoring.

Let's take a deeper look at these programs that are pointing the way into the future for chemical engineering. (About 750 words in Section 1)

2. Frontiers in Chemical Engineering Education. In 2003 under the auspices of CCR and with financial support from NSF, MIT organized a series of three workshops to examine whether and how to improve the existing chemical engineering curriculum.[iii] As a starting point the attendees noted that chemical engineering is uniquely positioned at the interface between molecular sciences (including molecular biology), systems engineering and management. They constructed a set of core organizing principles of molecular scale transformations, multi-scale descriptions, and system synthesis and analysis to use to envision a new chemical engineering curriculum. Examples of systems that graduates might be developing and designing in the future are

– hot-filament chemical vapor deposition
– microreactors
– chemotherapy drug delivery wafers
– multiply layered materials for microdevices and coatings

The attendees suggested also that "the curriculum should be consistently infused with relevant and demonstrative examples of open-ended problems and case studies, and challenges of engineering practice – safety, economics, ethics, regulation, intellectual property and market/social needs."

With this in mind the attendees proposed a new set of courses for the chemical engineering curriculum – quite different from the standard curriculum that many schools currently use.

Sophomore Year

– Molecular Basis of Thermodynamics
– Classification of Molecules
– Molecular Basis of Reaction Rates
– Interfaces and Assemblies
– Homogeneous Reactor Engineering
– Introduction to Systems

Junior Year

– Molecular Basis of Reaction Rates
– Molecular Basis of Other Properties and Constitutive Equations
– Descriptions of Reactive Systems
– Introduction to Molecular Systems

Senior Year

- – Special Topics (Electives)
- – Beaker-to-Plant Implementation of Multi-scale Principles for Product and Process Design
- – Systems and the Marketplace

The challenge to develop such a broad new curriculum as the one envisioned by MIT is immense. The expense of preparing a comprehensive set of new instructional modules will be considerable. The organizers of the three 2003 workshops continue to hold workshops – the last being at the 2005 AIChE Annual Meeting in Cincinnati – at which the shape of a sponsored program to convert the vision of the group into action is being developed.

It should be emphasized that most colleges and schools will likely make only incremental changes to their curricula along these lines. They will take the position that the molecular approach gives too little emphasis to specific unit processes. They will continue to ground their curricula on traditional lines that include standard courses, such as those in fluid mechanics, heat transfer, mass transfer and reaction engineering. They will not ignore the multi-scale approach, but will alert their students to the possibility of bringing molecular and process scales together.

A special aspect of new approaches to the curriculum that is growing in importance is the embedding of computerized computational techniques in the curriculum. The CACHE Corporation is leading the way on this. On the corporation's website may be found a comprehensive survey on "teaching computer programming, software selection, mathematical modeling instruction, teaching process and product design. Appendices include a recent survey of computing practices in industry and descriptions of integrated computing approaches at selected departments."[iv]

(About 500 words in Section 2)

3. The Pillars of Chemical Engineering. The Division of Engineering Education and Centers in the NSF Directorate of Engineering annually awards Grants for Department-Level Reform of Undergraduate Engineering Education.[v] According to its webpage, this grant program "supports departmental and larger units to reformulate, streamline, and update engineering . . . degree programs; develops new curriculums for emerging engineering disciplines; and meets the emerging workforce and educational needs of U.S. industry. These efforts should increase the relevance of undergraduate engineering curriculum to modern engineering practice . . . ."

For example, in 2002 a grant was awarded by this program to the Chemical and Petroleum Engineering Department of the University of Pittsburgh for the development of a new curriculum, entitled "Pillars of Chemical Engineering: A Block Scheduled Curriculum."[vi] This new curriculum, being developed principally by Pittsburgh chemical engineering faculty, will allow students "to integrate their knowledge across courses, disciplines [and scales of activity (molecules to chemical plants)] so that they are better prepared to address open-ended problems."

A key element of the new curriculum is the use of block scheduling. In block scheduling the hours devoted previously to two or three standard courses in one term are "blocked" into one course with considerably longer contact hours. Topics in this blocked course can be woven together in an integrated fashion, thus connecting them not only in an intellectually satisfying manner, but also in the way they are encountered in practice. Many of today's undergraduates have grown up with this method of organizing a curriculum during their earlier educational experiences.

Blocked courses are made up of a series of modules. In the Pittsburgh version, modules will be based on the standard "core of chemical engineering (including mass balances, thermodynamics, kinetics, separations, transport phenomena, process systems, control, laboratory, and design)." Using modules allows the integration into the curriculum of diverse elements, many changing with time, such as modules that may eventually be developed by the Frontiers in Chemical Engineering Education initiative. (About 300 words in Section 3)

4. ABET EC2000 and Criteria for Chemical Engineering. In response to calls for more flexibility in the criteria for accrediting engineering educational programs, ABET formulated in the late 1990s a new paradigm for accreditation criteria, EC2000.[vii] The new paradigm emphasizes application of continuous improvement methods for engineering programs based on educational outcomes (student learning results). The old paradigm was based on the inputs to the educational process through specific curricular requirements, quality of facilities, etc. The new general engineering criteria apply to all engineering programs and each program has criteria specific to the area. An important aspect of EC2000 is the requirement that the curricular design and its objectives be jointly developed with constituents, eg. industry, parents, students, faculty, etc. Evolution of the program curricula must depend on these constituents.

The chemical engineering program criteria that were first established under EC2000 were rooted in the traditional view of the needs of a chemical engineering graduate.[viii] Those program criteria specified that they were for "chemical engineering" programs, based on the notion that the name applied to all variations that still met the following criteria:

> These program criteria apply to engineering programs including "chemical" and similar modifiers in their titles.
>
> 1. Curriculum
>
> The program must demonstrate that graduates have: thorough grounding in chemistry and a working knowledge of advanced chemistry such as organic, inorganic, physical, analytical, materials chemistry, or biochemistry, selected as appropriate to the goals of the program; working knowledge, including safety and environmental aspects, of material and energy balances applied to chemical

processes; thermodynamics of physical and chemical equilibria; heat, mass, and momentum transfer; chemical reaction engineering; continuous and stage-wise separation operations; process dynamics and control; process design; and appropriate modern experimental and computing techniques.

Last year new chemical engineering program criteria were proposed by the AIChE Education and Accreditation Committee and were approved by the AIChE board and subsequently by the ABET board. These new criteria, which cover "chemical, biochemical, biomolecular, and similarly named programs", become effective in 2007. The criteria are as follows:

> These program criteria apply to engineering programs which include “chemical”, ‘biochemical”, “biomolecular” and similar modifiers in their titles.
>
> 1. Curriculum
>
> The program must demonstrate that graduates have a thorough grounding in the basic sciences including chemistry, physics, and biology appropriate to the objectives of the program; and sufficient knowledge in the application of these basic sciences to enable graduates to design, analyze, and control physical, chemical, and biological processes consistent with the program education objectives.

The long desired flexibility was provided by the new program criteria since the long list of required subject areas was reduced to a much more general output basis and made subject to the objectives of the program. The new criteria also protect the chemical engineering interest in various kinds of bioprocess-based curricula. ABET organized a team to consider the division of responsibilities for various biologically oriented programs -- presently bioengineering, biomedical engineering, biological engineering, biochemical engineering, and biomolecular engineering. ABET evaluators from AIChE will have specific responsibility for biochemical and biomolecular engineering and programs that emphasize process and molecular design. Bioengineering and biomedical engineering are the responsibility of the Biomedical Engineering Society (BMES). Biological engineering is the responsibility of the American Society of Agricultural Engineering (ASAE). (About 600 words in Section 4)

5. Chemical Engineering and Bio-related Engineering P.E. Examinations. Before graduate engineers are admitted to the public practice of engineering, state laws require that they take and pass the Professional Engineering Examination in their discipline. The examination for each discipline is prepared by NCEES[ix], according to a set of specifications which are updated once every eight years or so. Revised specifications are based on an extensive survey of hundreds of practicing engineers to determine the current professional activities and knowledges needed by graduates to practice engineering competently. The knowledges needed are both broad core knowledges as well as emerging knowledges – typically similar to the ones being added to the curricula by the

undergraduate faculty under the guidelines of ABET. During the last update of the specifications for the chemical engineering examination in 2003, topics in thermodynamics were transferred from a previous section devoted exclusively to this subject, and distributed throughout other sections where thermodynamics is viewed as a fundamental concept applicable throughout the practice of chemical engineering. In this update, complex processing systems, such as fluid-bed reactors, were given greater prominence. Also, topics related to the operation of chemical facilities were added, such as operating manuals (e.g., startup, shutdown, maintenance), performance of scheduled audits (e.g., testing safety valves, checking rupture disks), industrial hygiene and the design of pressure vessels per ASME Section VIII.

The committees that prepare the semi-annual P.E. examinations are charged to write questions that meet the current specifications. Thus, the future of chemical engineering is an element of the P.E. Examination in Chemical Engineering. Unfortunately, the actual content of these examinations is proprietary and can only be viewed by those writing and taking them. Therefore, only the specifications and a booklet of sample questions and solutions, which are publicly available, can be used by the general engineering community as one additional guide to the future of the disciplines.

Occasionally a significant new domain of engineering emerges that is given a distinct set of criteria by ABET, that experiences the development of one or more individual technical societies (or sub-societies) in the domain, and in which ten engineering licensing boards request that a licensing examination be given. Under these circumstances a new P.E. Examination may be created. The bio-related engineering area, which was discussed in the previous section, is currently in this situation. In August 2006 NCEES hosted a Bio Summit where representatives of six societies – AAEE, AIChE, ASABE, ASME, BMES, and IEEE – met to consider a Bio-related Engineering P.E. Examination. The boards of directors of the six societies are currently examining a prospectus that details a three-year project to validate the concept, set the specifications and prepare a first P.E. examination in this new field of engineering. If there is sufficient support from the boards of directors of these six societies – and from ten state engineering licensing boards – then a consortium of societies will begin work to establish this new examination by 2010. (About 450 words in Section 5)

6. AIChE Education Services Program. There are three purposes for continuing education courses offered by the AIChE Education Services Program that are described in the current catalog, located on the AIChE website.[x]

(1) Expose chemical engineers to an emerging area of practice. Examples are CH401 Bioseparations: Principles, Applications and Scaleup, and CH611 Six Sigma for Chemical Engineers.

(2) Refresh and update chemical engineers who are shifting their practice from one domain to another within the discipline. Examples are CH004 Distillation in Practice, CH294 Heat Exchanger Design and Operation, and the courses in Process Safety.

(3) Introduce non-chemical engineers, who support chemical engineers in their practice, to the fundamentals of chemical engineering and the characteristics of chemical processes. Examples are CH023 Fundamentals of Chemical and Petroleum Processes for Non-Engineers, and CH024 Chemical & Bioengineering Fundamentals for Technical and Scientific Professionals.

One of the charges of the AIChE Education Services Committee is to develop new courses that fit the first purpose. To that end the committee is currently working with prospective instructors for “Fischer-Tropsch Catalysis: Fundamentals and Practice,” “Microprocess Engineering,” and “Size Enlargement of Powders and Bulk Materials by Agglomeration.” The committee welcomes proposals from AIChE members for other new courses in emerging areas.

In the future more and more vehicles for maintaining continuing professional competency will be computer-based and web-based. For a number of years the AIChE Continuing Education Committee (the precursor of the Education Services Committee) encouraged the development of self-study courses delivered by CD-ROM. In the current catalog are seven courses in this mode.

- ZAC001 Distillation in Practice for Engineers
- ZAC002 Distillation Technology for Operators (English)
- ZAC003 Distillation Technology for Operators (Spanish)
- ZAC004 Industrial Fluid Mixing for Engineers
- ZAC005 Fluid Mixing Technology for Operators
- ZAC006 Essentials of Chemical Engineering for Non-Chemical Engineers
- ZAC007 Essentials of Chemical Engineering for Operators

Recently an on-line course has been added to the AIChE catalog from the ASME catalog – ZI140 “Two Phase Flow and Heat Transfer.” Another one is being developed from CH024 “Chemical & Bioengineering Fundamentals for Technical and Scientific Professionals.” Its first delivery is planned for an international client early in 2007.

An emerging technique that is now available on the AIChE website is the webcast (or webinar). The Education Services Committee is exploring the possibilities of this technique for offering advanced seminars on state-of-the-art topics, such as the webcast in September 2006 on “Modeling and Design of Multiscale Chemical Systems.” Those preconference courses, being offered by the AIChE Program Committee at the annual and spring national meetings that are not ready for development as public courses, are obvious candidates for webcasts. (About 450 words in Section 6)

7. Global Aspects.

Globalization has affected the practice of engineering in the U.S. Many engineering companies have become global enterprises. As indicated in Section one the profession of chemical engineering continues to evolve. However the rate of change has been significantly accelerated by globalization. Chemical engineers today need different skills to those required fifteen years ago. For example, engineering teams are often multi-national in composition. This means that teamwork has become even more important and now demands the ability to work with engineering colleagues from different cultures – requiring knowledge and sensitivity of multicultural issues.

A survey of undergraduate engineering curricula across the U.S. indicates that many schools are responding to the globalization of chemical engineering. Examples of the global emphasis chemical engineering degree programs include the international internships opportunities offered by MIT[xi] and the dual degree program between the University of Rhode Island and the Technische Universität Braunschweig (Germany)[xii] as well as numerous other study abroad programs.

In the future many more chemical engineering departments will develop "global options" programs within their undergraduate degrees as well as international research experiences for graduate students. These changes are being actively promoted by funding agencies such as NSF through its Partnerships for International Research and Education (PIRE) program[xiii]. Development of a global emphasis in chemical engineering programs will be essential in order for US chemical engineers to be competitive in a global environment. (About 250 words in Section 7)

8. The Future of Chemical Engineering. The future of chemical engineering truly is the set of sophomore students stepping across the threshold of their first course in chemical engineering. One good prediction of the "future of chemical engineering" can be made by examining the elements of the complete process of preparing them to enter into and continue their professional practice. This article has provided the roadmap for that examination. (About 50 words in Section 8)

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[i] Committee on International Cooperation in Engineering, Strengthening U.S. Engineering Through International Cooperation: Some Recommendations for Action. 1987, National Academy of Engineering and Office of International Affairs, National Research Council: Washington, D.C. p. 68.
[ii] McKinsey Global Institute, The Emerging Global Market: Part I -The Demand for Offshore Talent in Services. 2005, McKinsey Global Institute: San Francisco, CA. p. 343.
[iii] http://mit.edu/che-curriculum/
[iv] "Computing through the Curriculum: An Integrated Approach for Chemical Engineering," CACHE Corporation; http://www.che.utexas.edu/cache/Edgar-computing%20through.html
[v] http://www.nsf.gov/pubs/2005/nsf05531/nsf05531/htm
[vi] http://granular.che.pitt.edu/curriculum/
[vii] http://www.abet.org/Linked%20Documents-UPDATE/White%20Papers/Engineering%20Change.pdf
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