ChE views and opinions

FUTURE DIRECTIONS IN CHEMICAL ENGINEERING EDUCATION

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WE ARE IN THE middle of an extraordinary time of change, both in the explosive growth of new opportunities and in the restructuring of older industries. How should we educate our students so they will be effective in solving the most important problems of tomorrow?

Perhaps the number-one problem in America today is how to keep our industries competitive in the world. We have seen our commanding lead in cutting edge technologies vanish in industries such as textiles, steel, consumer electronics, and automobiles, and weaken in industries such as computer chips and high purity chemicals. Currently, America has only two industries that enjoy a healthy surplus of export over import: the manufacturing of commercial airplanes and of chemicals. We have a current export surplus in chemicals of about eight billion dollars, so we are still above water, but how long can we keep this lead? Why are Boeing and the chemical companies better than the rest? It may be that these companies see themselves as technology companies, try to gain competitive advantages through research and innovation, and are managed by people committed to technological leadership.

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Many reasons are given for the decline of once mighty American industrial power:

- **Corporate capital is in the hands of funds managers and corporate raiders who are interested in quick profit rather than long term strength.**
- **Corporate managers lack long-range vision and commitment in investing in cutting edge technologies.**
- **There is government interference by EPA, OSHA, FDA, and the anti-trust division of the Justice Department.**
- **The labor force is lazy, overpaid, and lacks commitment and work ethics.**

It is interesting that there is little or no complaint that America's decline is due to the inadequate education of engineers. However, there is no reason to be complacent, and we should continue to expand the knowledge and tools that our graduates need to be armed with as they formulate and solve problems.

WE NEED A NEW PARADIGM

Since the role of chemical engineers is changing fast, it would be well to spend a moment in discussing who they are. Chemical engineers are defined by what they know and what they do. Their knowledge is gained through the undergraduate curriculum and through their work experience in the chemical processing industries. Chemical engineers make things through chemistry. They also build plants, make equipment, teach students, provide government services, clean up the environment, study physiology, and make artificial organs.

The principal homes of the chemical engineers are the chemical and petroleum refining industries, shown in Table 1. They can also be found in the more extended chemical processing industries, which employ 27% of all manufacturing labor and provide 37% of all manufacturing value added. They share their professional work with scientists and other engineers, but without their contributions the US economy would collapse.

TABLE 1
The U.S. Chemical Processing Industries, 1984

INDUSTRY	EMPLOYEES THOUSANDS	VALUE ADDED $ MILLION	VALUE OF SHIPMENT $ MILLION
Chemical	843	94,728	198,233
Petroleum	137	16,163	189,011
Food	1,437	98,037	300,012
Paper	613	40,885	94,814
Rubber	732	34,183	69,512
Stone, Clay	533	27,707	53,405
Primary Metal	805	42,291	119,089
Total Manufacturing	19,140	963,646	2,253,847
Chem. & Pet. as %	5	12	
CPI as %	27	37	

Value Added = Wages and salaries of employees, plus interest and dividends to capital, plus depreciation, plus corporate income taxes (but does not include purchases of goods and services from other firms)
Source: U.S. Statistical Abstract, 1987.

TABLE 2
Current Employment of AIChE Members

MANUFACTURING		
Chemicals and Allied Products	34.1%	
Petroleum, Coal, Gases	13.8%	
Electronics	3.1%	
Food	2.5%	
Primary Metals	2.0%	
Process Equipment	2.0%	
Paper and Forest Products	1.7%	
Stone, Clay, Glass	1.1%	
Rubber	1.0%	
Other Manufacturing	13.9%	
		= 75%
SERVICES		
Engineering Design, Construction, Consulting	12.0%	
Government	4.8%	
Education	3.7%	
Nuclear Energy	2.8%	
Public Utility	1.3%	
		= 25%

Source: AIChE Economic Survey 1986
Note: "Chemicals" include: industrial chemicals, agricultural chemicals, paints, petrochemicals, pharmaceuticals, soaps, plastics.

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To get a clearer picture of the current employment of chemical engineers, let us turn to a study done by the AIChE in 1986 and shown in Table 2. Three quarters of AIChE members are employed in manufacturing, and nearly half of the members are employed in the chemical and petroleum industries. Electronics is the fastest growing field, outstriping the mighty food industry. One quarter of the members are in services. It may be a surprise that government employment is greater than education.

The National Research Council study on "Chemical Engineering Frontiers: Research Needs and Opportunities," chaired by Professor Neal R. Amundson of the University of Houston, became available in November 1987. It declared that there are four major areas of opportunity:

(1) The development of new high tech industries that are driven by scientific breakthroughs
- biotechnology
- electronic, photonic and recording materials and devices
- advanced materials

(2) The rejuvenation of traditional technologies
- energy
- raw materials

(3) The protection of health, safety, and environment

(4) New engineering sciences, concepts, and tools, such as
- computers, artificial intelligence
- surfaces and interfaces

In response to these new opportunities, chemical engineers need to revise their bag of tools and knowledge. The word "paradigm" was coined by Thomas Kuhn to mean a constellation of characteristics that set a profession apart from other professions, such as:

- a characteristic set of problems that the profession deals with
- systematic knowledge and methods that are effective in solving these problems
- a set of classical cases of successful solutions that are admired and studied
- stable textbooks, curriculum and accreditation, handbooks
- exchange of ideas through meetings and journals
- professional societies for the members to get together to govern themselves and to set common goals

When the first chemical engineering curriculum in the US was established by Lewis M. Norton at MIT in 1888, the curriculum consisted of little but industrial chemistry courses that were specific to each sector, such as soap, turpentine, and salt. The first chemical engineering paradigm was unit operations, which was embodied in the texbook *Principles of Chemical Engineering* by Walker, Lewis, and McAdams and published in 1923. It declared that any chemical process can be analyzed as a collection of unit operations such as distillation and heat transfer. Thus the proper study of chemical engineers is the study of these individual units, which can be assembled to form any process. This fiat turned chemical engineering into a systemic profession where the students have powerful tools to solve manufacturing problems. It also codified how knowledge should be organized, and how research should be conducted, and of course, how courses should be taught.

Unit operations provided many valuable research problems for chemical engineers for four decades, while rapid advances in knowledge and tools helped in the birth of the modern petroleum refining and the commodity chemical industries. Many chemical engineers became so successful in solving crucial problems in their industries that they were elected to be presidents and chairmen of the mightiest companies in the world. The gradual exhaustion of important and scientifically accessible problems after the second World War did not mean that unit operations could not be revived by the application of new and more powerful tools. The handling of solids and granular material remain a disgrace in our inability to predict and to scale-up, and separation is enjoying a resurgence once again.

The second chemical engineering paradigm of transport phenomena arrived in 1960 in a textbook by Bird, Stewart and Lightfoot. This approach declared that the proper study of chemical engineers is the molecular phenomena that are fundamental to the understanding and performance of chemical equipment. The kinetic theory of gases and Newtonian fluid mechanics particularly play central roles in this approach. Once again, many chemical engineering researchers are fully occupied in solving problems in this arena. This approach is so successful that we often look upon prior achievements as largely empirical and lacking in mechanistic understanding.

We are ready now for the birth of the third chemical engineering paradigm, a new way to state what are the most important problems that we should study, and what tools should be used to study them. We deal with problems and solve them at three vastly different scales:

(1) ***The microscale of molecular and aggregate level. Subjects in this scale include thermodynamics, transport phenomena and kinetics. These subjects describe the most fundamental chemical properties of matter, and they form the core of the scientific basis of chemical engineering.***

(2) ***The mesoscale of process equipment. We have courses in unit operations and in reaction engineering. In this scale, we synthesize many elements from the microscale to design and operate process equipment efficiently and reliably.***

(3) ***The macroscale of plants and systems. Here we are concerned with plant design and economics, product properties and market needs, safety and environment, productivity, and world competition. These are very important topics, but so far we have few courses that will give students a head start in dealing with them.***

Our colleagues, the chemists, deal mainly in the microscale, and the mechanical engineers deal mainly with the mesoscale. But practicing chemical engineers must deal with all three levels. The first paradigm of unit operations is in the mesoscale, and the second paradigm of transport phenomena is in the microscale. We need seminal courses in the macroscale, so that our students will have competitive advantages in dealing with the bigger picture. A new paradigm is waiting to be born.

NEW DIRECTIONS IN COURSES

As a consequence of new trends, the problems that face future chemical engineers will be different from today's problems. In addition to the classical problems of commodity chemical manufacturing, they will face a host of new problems. We must revise the curriculum so that they will have the necessary concepts and tools. I have listed the enduring and new problem

TABLE 3
Problem Areas for Chemical Engineers

ENDURING EMPHASIS	NEW EMPHASIS
• Small Molecules, Gases and Homogeneous Liquids	• Large Molecules, Complex Liquids and Solids
• Inorganic and Organic Chemistry	• Biochemistry, Material Science, Condensed State Physics
• Inexpensive and Large Volume Commodity Chemicals	• High Value Added and Small Volume Specialty Chemicals
• Undifferentiated Products with Long Life Cycles	• Proprietary and Differentiated Products with Short Life Cycles
• Dedicated Plants with Continuous Processing	• Flexible Plants with Batch Processing
• Innovations Dominated by Process Improvements to Save Costs	• Innovations Dominated by Product Development for Improved Product Performance
• Mesoscale of Process Equipments	• Microscale of Molecular Aggregates, Macroscale of Plant Productivity, World Competition, Safety and Environment
• Science and Technology	• Environmental and Society Concerns, Ethics, Humanities

areas in Table 3. What is important in petroleum refining and petrochemicals will still be important in the decades ahead, but we must not neglect the new emerging problem areas.

How do we deal with all these new forces? We may revise existing courses, we may develop new courses, and we may change the degree program. Much of the reform can be accomplished by changing the content of the existing courses. In the traditional courses, we illustrate the power of chemical engineering concepts by solving manufacturing problems. In the 1923 text of *Principles of Chemical Engineering*, the examples are largely drawn from the utilization of coal as raw material. The textbooks in the 60's and 70's are heavy with the solution of manufacturing problems in petroleum refining and in commodity petrochemicals. These chemical engineering principles can also be illustrated by manufacturing problems from the emerging technologies. There are several efforts underway to develop such course materials for the classroom use of teachers who are familiar with the principles but not with the applications in these new industries. A set of suggested directions of existing courses is listed in Table 4.

We also need new courses to broaden the horizons of our students. It would be desirable to have senior electives in the emerging technologies for students who want to go in these directions, such as in biotechnology, microelectronics, and advanced materials. It is increasingly difficult for chemical engineers to solve manufacturing problems if they are not familiar with surface and colloid chemistry and with polymer science and engineering. So many of our problems are concerned with surface and interface forces, with complex fluids stabilized by surfactants or polymers, with emulsions and micelles, and with the properties of polymers, that one is tempted to say that such courses should be required.

TABLE 4
Direction of Existing Courses

ENDURING EMPHASIS	NEW EMPHASIS
THERMODYNAMICS	
Small Molecules	Large Molecules
Gases and Simple Liquids	Complex Liquids and Solids
Kinetic Theory of Gases	Statistical Mechanics
TRANSPORT PHENOMENA	
Gaseous Diffusion	Configurational Diffusion
Knudsen Diffusion	Liquid and Solid Diffusion
Newtonian Fluid Mechanics	Non-Newtonian and Polymeric Fluid Mechanics
KINETICS	
Homogeneous Gas Reactions	Solid-Fluid Reactions
Catalytic Reactions	Biochemical Reactions
	Polymerization
SEPARATION	
Distillation of Oil	Protein Separation
	Ultra High Purity
	Membranes
REACTION ENGINEERING	
Dedicated Continuous Reactors	Flexible Batch Reactors
Oil and Petrochemicals	Polymers, Biotechnology, Electronics
Maximize Yield and Product Selectivity	Minimize Hazards and Harmful Emissions
DESIGN	
Processes	Products
Economic Efficiency	Product Quality
	Safety, Environment

We also need courses in the macroscale, so that students will be familiar with the "Big Picture" of how chemical engineers can fill the needs and expectations of society. *The ultimate justification of chemical engineers is their contribution to society:* they can develop products that society wants to buy at desirable quality and price, they can improve productivity and help their companies compete in the world, they can maintain high professional ethics, and they can protect fellow workers and the public from toxic substances and accidents. An increase in the humanities and social sciences would sensitize the students to the needs of the world.

One of the most urgent tasks is the development of courses in "Product Engineering." Alone among the engineering fields, the heart of chemical engineering education is concerned with processing, and we wait for someone else to develop a product and for the summons to scale-up the process. A product must have customers, and marketing is the tool to find out what customers want. It is the task of product engineers to design or to discover products with the desired characteristics. In other disciplines, aeronautical engineers design airplanes and space ships, electrical engineers design transformers and computers, civil engineers design bridges and structures, and mechanical engineers design compressors. In recent years, many chemical engineers have become increasingly involved in the design of catalysts, polymers, and numerous other products, but this has not yet been crystallized in one or more seminal courses in product design. As product cycles become shorter, many products become obsolete so quickly that a next generation process is not needed. Product engineering may be where future action will be, and our students need the training to make them effective in this important arena.

One may argue that there is little in common between the product chemistry and engineering of lubricating oil and cosmetic soap, so that one is reduced to teaching industrial chemistry in the old boring way.

The key to product engineering must be a set of principles that would be common to all product development and design. Perhaps the principles involve the relation between molecular and aggregate structure on one hand, and product properties and performance on the other hand, as well as how processing affects these structures and properties.

THE DEGREE PROGRAM

It is easy to agree that chemical engineers will have to know much more to solve problems in the future. How can we squeeze more content into the same four-year bachelor's degree program? In fact, the four-year BS is fast becoming fiction on many campuses. It is not at all uncommon, in going over transcripts, to find that the average number of years from freshman to graduation is close to five years in many colleges. The schedule is so rigid that anyone who wants to have a little fun in college, to join the ROTC, to play in the band, or to change majors, will have to pay the price of five years.

We have the traditional assumption that the first professional degree is the four-year BS. Students learn the fundamentals in universities in four years, then work in industry as apprentices to experienced senior engineers for a few years to gain the necessary knowledge to become full-fledged independent engineers. This assumption is also running into problems, as traditional industries are reducing senior staff and emerging industries do not have experienced senior staff to teach the new graduates. We count on about a quarter of our BS students going to graduate school for advanced training, but a shrinking percent of top U. S. students are choosing this path and we are becoming heavily dependent on immigrants for teaching and research. Are we following in the path of the Boston Symphony Orchestra, where an American-born is an oddity? The graduate schools of business, law, and medicine are taking an increasingly heavy toll from the top of our graduating class. Is this due to the two track system in industry where the fast track leads to management and the slow track leads to senior engineers? How can we deal with these problems?

Let me propose a realistic scheme which may be the basis for a new consensus. The first "professional" degree should remain the four-year BS which provides general education suitable for a variety of career paths. Without further specialization and schooling, such a degree would be sufficient for light technical work such as marketing, personnel, administration, production, and planning. To be effective in heavy technical work such as design, process development, and construction, the graduate needs either an MS degree or considerable apprenticeship with senior engineers and continuing education. For a career in teaching and research, a doctoral degree would be needed. Let us give up the pretense that we can adequately pack enough education into four years (given the high school graduates that we get) to train a student for heavy technical work immediately after the BS degree. Let us consider the four-year BS as general preparation for a number of exciting careers and further education in chemical engineering. □

ChE book reviews

PRINCIPLES OF ADSORPTION AND ADSORPTION PROCESSES

by D. M. Ruthven
Wiley-Interscience, Somerset, NJ 08873; 1984.
433 pages, $49.50

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Adsorption has become a key separations tool and an important unit operation in the chemical industry. Yet, with the exception of a very brief (but excellent) coverage on adsorption in King's *Separation Processes* and in the recent new edition of *Unit Operations of Chemical Engineering* by McCabe, Smith, and Harriott, this important process has been largely overlooked in our undergraduate texts and curriculum. Ruthven's book is a timely addition to the chemical engineering library and, hopefully, will stimulate interest in both teaching and research on this subject.

Many books exist on the physical chemistry of adsorption. This is the first book bridging the gap between chemistry of adsorption and its engineering applications in separation and purification. It is not surprising that Ruthven wrote this book because he is one of very few who has done research on all aspects of adsorption, ranging from thermodynamics and transport processes to adsorber design and cyclic adsorption processes.

The book gives a complete (although not even) coverage of all aspects of adsorption: adsorbents, sorbent characterization, thermodynamics and energetics of adsorption, pore diffusion, transport processes in fixed-bed adsorbers, adsorber dynamics and cyclic adsorption processes. The author speaks with authority