ChE perspective

CHEMICAL ENGINEERING

Notes on Its Past and Its Future

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The history of chemical engineering education is important and should be recorded for the benefit of future generations of chemical engineers. It is equally important for us to consider where the future of chemical engineering education lies and what its demands will be. Both of these facets will be addressed in this paper.

Olaf Hougen gave an excellent account of the first seventy years of chemical engineering education at the 82nd National Meeting of the American Institute of Chemical Engineers,[1] and James Westwater later traced the roots of chemical engineering departments over the same general period in another well-researched paper.[2] Since these two papers give us an outstanding early history of chemical engineering education, I will use them to summarize the first seventy years.

THE PAST

Hougen gave an interesting description of his own early experiences in chemical engineering education in the introductory pages of his paper. When he began his studies, chemical engineering was unknown to the public and only feebly recognized by industry. The discipline had no resemblance to today's field of study. When he went to the University of Washington in 1911, he found there were no filter presses, no evaporators, and no distillation columns; there were no courses in unit operations, or in material and energy balances, or in heat and mass transfer, or thermodynamics, chemical kinetics, catalysis, process design, process control, and there was no equipment in the laboratory!

Hougen also indicated that "the use of higher mathematics beyond calculus was too time-consuming to be of practical value in solving engineering problems." There were no high-speed calculators, and the slide rule was a novelty. The library had some books on industrial technology, but they were written in German and required a reading knowledge of that language.

Hougen attempted to enroll in a course in the new field of biochemistry, but was shunted into a hydraulics course where he was told to design a sewerage system for a fictitious city. Hougen relates that his professor's instruction "consisted of trying to plan, and at times to solve, independent trouble-shooting problems through literature surveys, followed by experiments of our own devising." Some of the problems the students were given concerned finding out what caused corrosion of pipelines in the streets of Seattle, how acetone could be produced from the huge piles of sawdust in Washington, and how SO_2 could be recovered from Tacoma's smelter gases. On another occasion the students were asked "to determine the alcohol content of Ranier Beer"; Hougen reports that many bottles were required to complete this assignment (a distinct advantage over modern chromatography).

This method of teaching, and learning, was both challenging and stimulating. It taxed the students' ingenuity and resourcefulness, and it sustained their interest. It is one of the best methods of teaching, but as Hougen concluded, "large enrollments today, with strenuous lessons in theory, rarely permit this type of undergraduate instruction."

Massachusetts Institute of Technology is recognized as the first chemical engineering department (1888), with the University of Pennsylvania (1892), Tulane University (1894), and the University of Michigan (1898) all predating 1900. Hougen and Westwater agree on this time frame and defined the "beginning" of a chemical engineering department to mean that information in the university catalogs indicated that a degree could be obtained in the discipline.

Chemical engineering largely evolved from chemistry. If one accepts the term "industrial chemistry" to mean chemical engineering, then New Jersey Institute of Technology in 1881 and Case Western Reserve University in 1884 would be the first and second departments.

The developmental path of chemical engineering in many universities has been quite similar since most modern de-

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partments are outgrowths of chemistry departments. It took M.I.T. twenty years to become independently identified, and Westwater points out that at the University of Illinois it took sixty-nine years for chemical engineering to become an independent department.

Faculties were small in the early years. As late as 1909, Michigan had only two chemical engineering professors and one metallurgical engineering instructor. The Dean reported to the Regents, "No addition to the teaching force will be needed, and it is not expected that the number of students will be large."

Westwater also conducted a survey to determine how many departments had developed from chemistry departments, and to his list of fifty-five (shown in the first section of Table 1) I have added the University of Utah. He also found some chemical engineering departments that arose from departments other than chemistry, and they are listed in the second part of Table 1 with their origins noted in parentheses.

The University of Colorado's department, for example, came from mechanical engineering, offering a four-year curriculum in mechanical and chemical engineering. There was a common program for the first two years, followed by an option in chemical engineering. At Louisiana State University, the Audubon Sugar School was begun in 1897 with a curriculum in sugar chemistry and sugar engineering. It gradually shifted to chemical engineering and granted its first ChE degree in 1905. Sugar chemistry was also started at Tulane University, but it was not a success and was later abandoned.

One of the most interesting off-shoot departments is Cleveland State and its origins from a YMCA Extension program. Pre-evening classes were popular, and in 1890 engineering as mechanical drawing was added to the curriculum. In 1909 it became the Technical School and was later renamed YMCA School of Technology. In 1926 the school bulletin listed chemical engineering as a discipline with twenty-nine courses (twenty-five of them in chemistry, metallurgy, mineralogy, and metallography). It subsequently became known as Fenn College, and finally, Cleveland State University.

Westwater also found eighteen departments that were "free standing" from the beginning, and they are listed in the third section of Table 1.

Curriculum changes through the years were well docu-

TABLE 1

ChE Departments Originating from Chemistry Departments

University of Alabama	Kansas State University	New Mexico State University	University of Rhode Island
Arizona State University	Lafayette College	North Carolina State University	University of South Carolina
University of Arkansas	Lehigh University	Ohio State University	Stanford University
Brigham Young University	University of Massachusetts	University of Oklahoma	University of Tennessee
University of California, Berkeley	Massachusetts Institute of Technology	Oklahoma State University	University of Texas, Austin
California Institute of Technology	University of Michigan	University of Pennsylvania	Texas A&M University
Carnegie-Mellon University	Michigan State University	Pennsylvania State University	Tri-State University
Case Western Reserve University	Michigan Technological University	University of Pittsburgh	Tufts University
University of Cincinnati	University of Minnesota	Polytechnic University of New York	Tulane University
Cornell University	University of Mississippi	Pratt Institute	University of Utah
University of Detroit	University of Missouri, Rolla	Princeton University	Vanderbilt University
Drexel University	Montana State University	Purdue University	University of Virginia
University of Illinois	University of Nebraska	Rensselaer University	University of Washington
University of Iowa	New Jersey Institute of Technology	Rice University	Washington University

ChE Departments Originating from Other Departments

University of Colorado (Mechanical Engineering)	University of Rochester (Mechanical Engineering)
Cleveland State University (YMCA Extension)	University of Toledo (General Engineering)
University of Illinois, Chicago (Energy Engineering)	University of Tulsa (Petroleum Engineering)
Iowa State University (Ceramics & Mining Engineering)	University of Wisconsin (Electrical Engineering)
Louisiana State University (Sugar Engineering)	University of Wisconsin, Milwaukee (Energy Engineering)
Lowell University (Paper Engineering)	University of Wyoming (Petroleum Engineering)
McNeese State University (General Engineering)	

ChE Departments That Were "Free-Standing" From Their Beginning

University of California, Santa Barbara	University of Houston	Montana State University	State University of New York
University of Southern California	Howard University	Oregon State University	South Dakota School of Mines
University of Connecticut	University of Kentucky	Rutgers University	Syracuse University
University of Delaware	Lamar University	University of Southwestern Louisiana	West Virginia University
			Yale University

mented by Hougen. He looked at seven continuous decades and listed the new courses or increased emphasis that was apparent in each of the decades. He also listed the courses that were dropped and the principal developments of each decade. His list is shown in Table 2.

Hougen also identified what he felt were the three principle areas of chemical engineering over those seven decades: 1) industrial chemistry until 1920; 2) the major development of unit operations from 1920 to 1950; 3) chemical engineering sciences beginning in 1950.

It is also interesting to note the textbooks that appeared at the beginning of new specialized branches of chemical engineering over the six decades. Many of them helped initiate important developments during those years. They are:

- **Industrial Chemistry:** *Outlines of Industrial Chemistry,* by Thorpe (1898)
- **Unit Operations:** *Principles of Chemical Engineering,* by Walker, Lewis, and McAdams (1923)
- **Material and Energy Advances:** *Metallurgical Calculations,* by Richards, and *Applied Stoichiometry,* by Lewis and Radasch (1926)
- **Thermodynamics and Process Control:** *Thermodynamics for Chemical Engineers,* by Weber (1939)
- **Applied Kinetics and Process Design:** *Kinetics and Catalysis,* by Hougen and Watson (1947)
- **Transport Phenomena and Computer Technology:** *Transport Phenomena,* by Bird, Stewart and Lightfoot (1960)

Hougen also looked at the seventh decade of 1965-1975, but only at the University of Wisconsin, and found option courses in four branches: environmental, biomedical, polymers and plastics, and food processing. He closed with a consideration of the growth of science with a new teaching emphasis on research, largely scientific in nature. He stated in his bicentennial lecture

> *Seventy years ago chemical engineering was 99% art and 1% science. Today the profession is 50% art. There is a current tendency, especially among young instructors, to restrict engineering instruction to courses in mathematics and basic sciences, omitting conjecture based upon judgment, economics, and experiences. If this procedure were valid, there would be no need for colleges of engineering: all technical training could be left to the departments of mathematics and the basic sciences. In spite of the high confidence of sciences and mathematicians in their own specialties, they have rarely been entrusted with or interested in industrial design,*

TABLE 2
Important Changes in Undergraduate Education

Courses Added	*Principal Developments*	*Courses Dropped*
Decade I: 1905-1915		
Industrial Chemistry	Industrial Chemistry	Hydraulics
Metallography		Surveying
Applied Electrochemistry		Gas Manufacture and Distribution
Technical Analysis		Foreign Languages
Pyrometry		Reduction in Mechanics
Shopwork		Quantitative Chemistry
Chemical Manufacture		
Decade II: 1915-1925		
Unit Operations	Unit Operations	Descriptive Geometry
Decade III: 1925-1935		
Material and Energy Balances	Material and Energy Balances	Contracts and Specifications
Fundamentals		Reduction in Mechanics
		Machine Design
Decade IV: 1935-1945		
Che Thermodynamics	ChE Thermodyanmics	Reduction in Shopwork
Process Control	Process Measurements/Control	Industrial Chemistry
Increase in Physical Chemistry		Mechanics
Increase in Unit Operations		Steam and Gas Technology
Increase in General Chemistry		Applied Electrochemistry
Decade V: 1945-1955		
Applied Kinetics	Applied Kinetics	Industrial Chemistry
Process Design	Process Design	Metallography
Report Writing		Machine Design
Speech		Steam and Gas Technology
Decade VI: 1955-1965		
Transport Phenomena	Transport Phenomena	Graphics
Physical Measurements	Process Dynamics	Shopwork
Differential Equations	Process Engineering	Reduction in Unit Operations
Computer Programming	Computer Technology	Material and Energy Balances

construction, and plant operations. These responsibilities belong to the engineer.

He also quoted Bob Marshall, former Dean of Engineering at Wisconsin, who said

The science syndrome among some of our engineering faculty has resulted in engineering graduates being unprepared and unmotivated to participate in the real world of engineering practice. Engineering is substantially broader and more challenging in scope than the sciences! I am sure that this argument and concern in chemical engineering is not finished and will continue on far into the future.

Hougen also set out a list of twelve principles of teaching which have since become well known as "Hougen's Principles." They are enumerated in Table 3 with corresponding comments by R. Byron Bird, originally written as a Memoriam to Olaf Andrus Hougen.

What has happened to chemical engineering education since 1965. A lot! First we have greatly increased the breadth of the technology we cover in our individual discipline. At the same time, we compete with many other engineering

TABLE 3
Hougen's Principles and Bird's Memmoriam Comments

Hougen's Principles	*Bird's Memoriam Comments*
1. The undergraduate program should be practical and conservative, whereas the graduate program should be imaginative and exploratory.	1. Professor Hougen clearly recognized that we have an obligation to train most of our undergraduates so that they can assume responsible jobs in industry. However, he also made it clear that at the graduate level we must be boldly pioneering in new fields.
2. There should be a smooth flow of information from graduate research to graduate teaching to undergraduate teaching.	2. We should not experiment on undergraduates by giving them untested material. Professor Hougen felt that every undergraduate course should be backed up by graduate course instruction and research so that the undergraduate program would always be under pressure to be modernized.
3. If you can't find relevant problems to give the student, then you shouldn't be teaching the material to the students.	3. Professor Hougen felt strongly that our teaching should emphasize topics which are useful for solving the industrial problems of the present and future.
4. Use the best available information from the modern sciences.	4. Good engineering analysis and design must utilize the most up-to-date material from chemistry, physics, and mathematics.
5. Well-founded and well-tested empiricisms are to be preferred over theories that have only a limited range of applicability.	5. He felt very strongly that every effort should be made to present results in the form that could be easily used by practicing engineers..
6. It is vital for engineers to know how to solve problems with limited and incomplete data.	6. One time Professor Hougen gave a seminar entitled "From Cork to Mollier." Everyone knew who Mr. Mollier was, but all efforts to discover the identity of Mr. Cork failed. The seminar dealt with the problem of predicting the Mollier diagram by sniffing the cork of the bottle containing the material! Professor Hougen's students certainly came away from his thermodynamics course fully aware of many clever methods for physical property estimation.
7. Students are impressionable and learn quickly, and therefore a professor must make certain that he teaches in a responsible way.	7. One time Professor Hougen called me on the carpet because, in a graduate seminar introduction, I had suggested that the speaker's new theoretical methods would soon replace the tried-and-true engineering correlations. He took issue with this, and said I had no right to make an unqualified statement of that sort in front of the graduate students and that I had left them with a totally incorrect impression.
8. It is important that the students have a good grounding in the basic fundamentals; there's nothing worse than a student who has a thin veneer of high-powered theory.	8. Whether or not students go into industry or on to graduate school, they appreciate being well grounded in the elementary ideas of the undergraduate subjects.
9. We must always recognize that our students and our teaching assistants are young professionals.	9. Students and young engineers of Professor Hougen always felt that he wanted them to share with him in the responsibility for the development of chemical engineering as a profession.
10. Recognize that faculty members have an obligation to assist colleagues in other institutions.	10. He recognized that the preparation of textbooks was a key responsibility for professors in leading research departments and he made substantial contributions to that area along with his colleagues Professors K. M. Watson and R. A. Ragatz.
11. We have, as faculty members in a state-supported institution, a responsibility to serve the taxpayers by performing our job well.	11. Professor Hougen often said that he felt that the citizens of the State of Wisconsin had been very generous in supporting our university and that we have a duty to perform our assignments as well as we can with the limited resources available.
12. Do not show emotions of bitterness or beratement or belittlement; ascribe the best motives to your associates; say nothing derogatory.	12. Those words, written in a note to himself, are sterling words of advice for the creation of a collegial atmosphere within a department.

disciplines. Table 4 shows the number of accredited U.S. engineering programs as of November 1991. There are 31 disciplines with 1432 accredited departments at the BS level. Engineering has become "splintered," and it is obvious that the disciplines compete with each other in many aspects.

In the mid 60s, we substantially reduced the number of credits required for graduation. Before the reduction, we required an average of around 18 credits per quarter, or around 216 quarter credits, for the BS degree. Today the average is about 16 credits per quarter, or around 192 credits in the quarter system. That is a 11.1% cut in the number of credits required for the BS degree—at the same time that we have more knowledge to impart!

This has led to the development of options in the curriculum. For example, at the University of Utah we have seven (down from a previous figure of nine) options: the Standard Chemical Engineering Curriculum, Fuels and Combusion, Applied Math and Physical Sciences, Biochemical Engineering, Environmental and Waste Engineering, Management, and Materials. While the reduction in required credits was engineered to remain competitive with other institutions, we must satisfy ABET requirements in all of the options.

The cost of education has also escalated dramatically. The University of Utah is on the lower end of tuition costs for state universities, but while the average rate of inflation for the years 1974 to 1992, according to the Comsumer Price Index, was 5.98%, the cost of tuition at the University of Utah during the same time period rose 8.56%. Even more dramatic, for the last 11 years (1982-1993) the inflation rate for tuition was 106% higher than the Consumer Price Index. Also, surveys indicated that over 70% of the students at the University of Utah had to work in order to attend school, and in engineering, it is even higher. The average number of years to obtain a bachelor's degree is 6.5 years—we seldom see engineering students graduating in 4 years. We are excessively extending the time it takes for a student to begin his or her working career, while at the same time injuring the quality of education they obtain by unnatural cost increases.

Another influence on today's education is the seriously fluctuating enrollments. Figure 1 shows the freshmen enrollment and the number of BS graduates in chemical engineering from 1973 to 1991. The figures are taken from the last survey reported by AIChE.

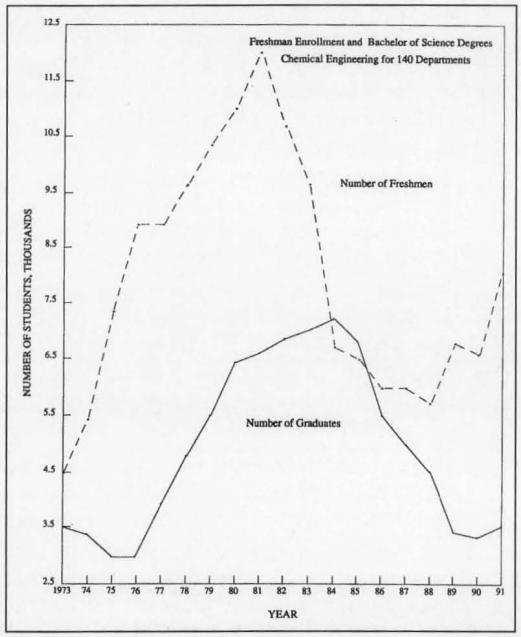

Figure 1. *Comparison of the number of freshmen and the number of graduates between 1973-1991.*

There is also a perception on the part of many professors that because of the present-day dominance of the federal government in education, through research grants, that promotions and salary increases now come from research, not teaching, that good teachers involved in research do less teaching, that too much time must be spent in proposal writing, effectively reducing teaching time, and that educators often emphasize their research area when teaching, sacrificing instruction in applications.

THE FUTURE

Any survey asking the question of how chemical engineering education should adapt itself to the future will have as many suggestions and

TABLE 4
Accredited Engineering Programs as of November 1991
(Source: 1991 Annual Report, ABET Engineering Accreditation Commision)

Program Area	*Bachelor's Level*	*Master's Level*	*Total*
Aerospace	57	4	61
Agriculture	46	0	46
Architecture	13	0	13
Bioengineering (incl. Biomedical)	20	0	20
Ceramic	12	0	12
Chemical	145	1	146
Civil, Construction	212	1	213
Computer	69	2	71
Electrical, Electronic	255	3	258
Engineering (Undesignated)	31	0	31
Engineering Management	2	1	3
Engineering Mechanics	9	0	9
Engineering Physics, Science	28	0	28
Environmental	11	8	19
Forest	2	0	2
Geological, Geophysical	18	0	18
Industrial	93	1	94
Manufacturing	10	3	13
Materials	30	0	30
Mechanical	234	2	236
Metallurgical	30	0	30
Mineral	3	0	3
Naval Architecture and Marine	12	0	12
Nuclear	25	1	26
Ocean	6	2	8
Petroleum	21	0	21
Plastics	1	0	1
Surveying	6	0	6
Systems	11	1	12
Welding	1	0	1
Other	6	0	6
Less Dual Titles Counted Twice	-5	0	-5
Total Accredited Programs	**1,432**	**30**	**1,462**

ideas as it does interviewees, but some basic ideas emerge. It is interesting to compare Table 5, which summarizes the ABET chemical engineering curriculum requirements of today, with Table 6, which lists the results of a poll of two hundred chemical engineering faculty conducted by AIChE Education Advisory Board in 1990. There seems to be good agreement between the two. But there are additional considerations along the lines of what to include within the various courses. For example, in the teaching of design there have been suggestions that we need to emphasize more problems and applications, that we need more open-ended problems with more than one answer, and that interaction with practicing engineers can help prepare our students for their careers.

TABLE 5
Summary of ABET Curriculum Requirements in Chemical Engineering

Quantitative

- 1.0 year of Mathematics (beyond Trigonometry and through Differential Equations) and Basic Science (including Chemistry and Physics)
- 1.0 year of Engineering Science
- 0.5 year of Engineering Design
- 0.5 year of Humanities and Social Science
- 0.5 year of Advanced Chemistry

Qualitative

- Appropriate Laboratory Experience
- Appropriate Computer Experience
- Knowledge of Probability and Statistics
- Competency in Written and Oral Communication
- Understanding of Ethical, Social, Economic and Safety Issues

TABLE 6
Poll of Two Hundred Chemical Engineering Faculty Members on What The Accreditation Criteria Should Be
(Source: 1990 Poll, AIChE Eductional Advisory Board)

	% Favoring Requirement
Overall Requirements Should Include at Least	
• 0.5 year, Humanities and Social Science	86%
• 1.0 year, Mathematics and Basic Science	92%
• 1.5 years, Engineering	87%
• 1.0 year, Engineering Science	70%
• 0.5 year, Engineering Design	62%
Basic Courses Should Include at Least	
• Mathematics through Differential Equations	96%
• General Chemistry	93%
• General Physics	89%
• One Design Course	88%
• Mass and Energy Balances	93%
• Fluid Mechanics	94%
• Heat and Mass Transfer	94%
• Separation Processes	88%
• Reaction Engineering	93%
• One Process Control Course	83%
• One Engineering Thermodynamics Course	74%
• 0.5 year, Advanced Chemistry	63%
• One Materials Course	54%
• One Biology Course	22%

How do we maintain increasing opportunities for chemical engineers in the global marketplace? Primarily by furnishing an outstanding education. It must have sufficient breadth and depth to prepare them for the ever-widening technology. Some of the many suggestions that have been advanced for effective teaching in the coming years include

- *More efficient use of education technology such as audio and video equipment*
- *A warning not to chase the emerging fields (biomedical, bioengineering, etc,) but to concentrate on chemical engineering—it's going to be around for a long time.*
- *Work more effectively with industry*
- *Go back to basics—every department doesn't need a course in control technology*
- *The global marketplace is the marketplace of the future and should be considered in all aspects of curriculum decision making*
- *The role of government intrusion, through research grants, into education should be carefully reviewed*
- *Give more consideration to the economic and political aspects of chemical engineering*
- *Be more flexible in scheduling for evening and part-time students*

Obviously, there are many areas of chemical engineering education which can and should be restructured to meet the demands of the future. We should also have a better understanding of what product quality should be and better input from the users of our products when making curriculum decisions.

CONCLUSIONS

Chemical engineering education has a rich history of progress, achievement, and success. This has come about because the profession and its educators have kept the technology and its application equal to the changes and challenges that have emerged. If we continue into the future with the same enthusiasm and concerted effort, we can maintain a strong, vigorous, and progressive system that serves it students, industry, and society well.

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