Chapter 7

Chemical Engineering Education at Purdue

The Undergraduate Curriculum

For its first 25 years, Purdue was recognized as a leading producer of industrial chemists and chemical engineers with Bachelor of Science degrees. For the past 100 years, Purdue has been recognized as one of the leading U.S. institutions in undergraduate ChE education. For the past 75 years it also has been recognized as a leading institution for graduate ChE education.

The success of the Purdue educational program is by many attributed to the ability of the faculty to adjust the program to changing industrial needs and to formulate a balanced curriculum containing both fundamentals and applications.

In Chapters 2 to 6 we have discussed the philosophical evolution of ChE education from the ideas of industrial chemistry (before 1923), to unit operations (1923), thermodynamics (1935) and reaction kinetics (1940), transport phenomena (1960), and then the current expansion of chemical engineering into biology and nanotechnology. Excellent articles by Hougenl[1,2], Aris[3] and Pigford[4] summarize the early educational developments in chemical engineering. At Purdue these ideas were of course known, but not always followed. This was either because of lack of personnel to teach the appropriate courses (during Peffer's administration) or because other educational emphasis, such as unit processes, prevailed (especially in the 1930's and 1940's).

An analysis of the ChE curriculum as described in the Bulletins of Purdue University shows that major changes occurred in 1934, 1947, 1964, 1972, 1981, and 2011. In between, there were continued minor changes but without large scale curriculum changes.

PURDUE UNIVERSITY.

CHEMICAL ENGINEERING.

Professor Peffer in charge.

1. Chemical Technology.-First semester.
2. Chemical Technology.-Continuation of 1.-Second semester.

Two lecture or recitation hours per week.
Required of Seniors in the School of Chemical Engineering.
Electives (if both are taken) for students in the School of Science.
Must be preceded by Chemistry 5, 6, .7, 8.
Accompanies Chemistry 9a.

The course treats of the practical application of chemical and physical principles to the problems of chemical manufacture, together with the principles of standard types of machinery and apparatus in use in the chemical industries.

Trade catalogues are used as much as possible to familiarize the student with the design and construction of the various types of apparatus. Professor Peffer.

3. Principles of Metallurgy.-First semester.
4. Principles of Metallurgy.-Continuation of 3.-Second semester.

Two lecture or recitation hours per week. Until 1014-15, this line of study will be condensed into one course. of two hours per week in the second semester.
Required of Seniors in the School of Chemical Engineering.
Electives (if both are taken) for students in the School of Science.
Accompanies Chemistry 9a and 10a or 10b.

A. study of the underlying principles of metallurgy as a whole, rather than a detailed description of operations ; includes fuels, furnaces, furnace efficiencies, thermo-chemistry, constitution of alloys, slags, etc., and the consideration of some of the most important metallurgical processes. *Professor Peffer.*

This space devoted to ChE courses in 1912 Bulletin of Purdue University.

During the early period of 1911-34 in undergraduate education, when Peffer was in charge of the School, there was a period of teaching of industrial chemistry practice with a gradual shift towards chemical engineering. The failure of Purdue to be included on the 1925 AIChE list of schools "rated as giving satisfactory courses in chemical engineering" accelerated the inclusion of chemical engineering courses in the curriculum. With the arrival of R. Norris Shreve in 1930 and Clifton L. Lovell in 1934, two strong poles of ChE education were formed: unit processes and unit operations. A third strong area, metallurgy, was under the direction of John Bray.

From 1934 to 1947 the emphasis of the ChE program was on these three areas. With the resignation of Lovell and the arrival of J.M. Smith in 1945 and Bennett and Myers in 1949 and 1950, respectively, major changes occurred in the curriculum. The period 1947-1964 is characterized by the slow emergence of transport processes from the old unit operations courses (Bennett and Myers), and the establishment of courses in thermodynamics (Smith) and kinetics (Smith and Woods). The number of courses on unit processes and organic chemical technology gradually decreased to two. From 1964-1972 there was an increased emphasis in process design, control and transport phenomena. The new areas removed many of the topics from unit operations, but one part of unit operations has survived with only evolutionary changes although it was renamed as separation processes. This period also saw a reduction in engineering requirements outside of ChE with a corresponding reduction in credits required for graduation from 144 to 131.

The 131 credits required for graduation survived until 2011 when the requirement was reduced slightly to 130. (The Purdue administration would be happy if the number of credits required for graduation in all disciplines stabilized at a uniform value of 120.) In 1981 the curriculum was rearranged and courses were renumbered: thermo and data analysis to sophomore year, separations from sophomore to junior year with an increase from two to three credits, and a slight increase in the required transport for all students. The period from 1981 until about 2000 is characterized by an emphasis on engineering science fundamentals in ChE, and a most ambitious schedule of ChE elective courses. After 2000, economic realities and increased undergraduate enrollment (particularly after 2006) plus increased pressure for more research have curtailed expansion of course offerings, although biology was added to the curriculum in 2003, despite the emergence of new areas of interest to chemical engineers.

National and Purdue trends in undergraduate curricula since the early 1980's are not totally clear. The need to integrate biology and chemistry into the curriculum has been widely understood[5-7]. Addition of a biology course in the curriculum (which was done by MIT, Univ. Texas-Austin, and Purdue among other schools) is relatively easy, but true integration of biology into the ChE core courses, although achieved at a few schools[8], has proven more difficult. The emergence of major biomedical engineering (BME) or biological engineering departments has not helped in this respect. A typical comment from professors who question the introduction of biology in ChE curricula is "students who want to learn biology should matriculate in BME departments". The use of options or concentrations has also been proposed[5,6] and partially adopted at some schools (including Purdue in a very modest way).

Because many schools (including Purdue) strongly believe that a unitary core of chemical engineering is necessary, the options are not as encompassing or wide-spread as their use in some other engineering disciplines such as electrical and computer engineering. Because the structure of the chemical industry has changed and because many chemical engineering graduates no longer find employment in the classical chemical and petroleum industries[9-11], there is a push to include product engineering. Graduates will need to be comfortable with producing products that function based on their micro- or nano-structure (the Purdue example is ChE 430 added in 1994, changed to 330, and made an elective in 2011). In addition, there will be more interest and need to teach batch processing (the Purdue example is the Pharmaceutical Processing option). Some detailed examples to teach product design are available[9,10], but product design does not appear to have been developed as a separate course; instead, it is often part of the capstone design course.

In 2010 AIChE included coverage of safety explicitly in the ABET criteria for chemical engineering programs. Purdue is including safety discussions in all core ChE courses with extensive coverage and assessments in the reaction engineering (ChE 43400) and capstone design (ChE 45000) courses. In addition, the safety elective discussed in Chapter 6 is popular. In order to achieve any of these changes on a national scale, ChE examples and textbooks need to be revised to include examples from a much wider variety of industries. Unfortunately, with very few exceptions, there are no young textbook authors with the energy and background to incorporate these changes in their textbooks. Textbooks are discussed in more detail later.

The first plan of study for chemical engineers (Appendix C) was created by Percy N. Evans, Head of Chemistry, in the fall of 1907. This plan was an effort to include some applied subjects in an almost purely chemistry-oriented curriculum. This was the plan of study with which the classes of 1909-1913 were educated. Courses in English, biology, organic chemistry, physics and mathematics were required. Some engineering subjects were taught such as mechanics, testing of materials, engines and boilers, and mechanical drawing, and there were introductory courses in electrical engineering and applied electricity. The main chemical engineering courses in the 1907-1908 plan of study were Chem 9, Industrial Chemistry and Chem 10, Technical Analysis, taught by Evans himself. Absent from this curriculum was physical chemistry. The 1909 *Bulletin of Purdue University* gives an interesting description of Chem 9 and 10.

> In these courses the lectures deal with the significance of procedure and results in the analysis of coal, gases, iron and steel, oils, cements, foods, fertilizers, water, asphalt, and other industrial materials; also assaying of gold and silver ores, metallography of iron and steel, and calorimetry of fuels.

This was Evans' idea of chemical engineering. Characteristics of the ChE curriculum which would continue for many years were the requirements of courses in the German language (initially six semesters!), mechanical drawing, engineering courses other than ChE, shop, biology, and military training. The German requirement survived the anti-German propaganda of World War I, but died out as the program embraced more chemical engineering and less industrial chemistry. Mechanical drawing, shop and other engineering were all slowly phased out. Military training survived until the Vietnam War when it was eliminated. Unfortunately, biology was removed and had to be reinstated in 2003.

A letter by Prof. Jack J. Hinman, Jr. of the Civil Engineering Department of the University of Iowa, written to Prof. John T. Fotos of the German Department of Purdue in 1939 elucidates the philosophy of education in those days[12].

> I was a member of the first regular class of chemical engineering at Purdue, entering in the fall of 1907. We were grouped (in German) into one section I think and given the same schedule as the students starting civil engineering. Our section had Professor Flügel, the head of the department as the instructor. We used Glück-auf and some German grammar (book) whose name I forget. The class work was about average I suppose.

> The second year we chemical engineering students had Professor John Gunn for instructor. The plan was to use Wait's German Science Reader in the first semester and a magazine, Die Well der Technik, in the second semester. The class appointed a committee to call on Professor Flügel and ask that we be given a chemical text instead. Our request was sympathetically received and copies of Grundzüge der Chemie and Mineralogie by Professor R. Arendt (1904) were ordered for us.

Finally, the 1907 plan of study (Appendix C) had a requirement for B.S. thesis work in the last semester of the senior year. This was probably equivalent to a primitive design project as judged by the introduction of Ferguson's thesis (B.S. '09) where it is stated that the results were obtained over a two-week period.

With Peffer's arrival the plan of study was reorganized (Appendix D) by the replacement of Chem 9 and 10 by ChE 1 and 2, Chemical Technology. These two courses were the predecessors of unit operations, but only vaguely did they resemble the courses that Lovell would introduce 20 years later. The 1911-12 Bulletin offered the following description of these senior courses.

> The course treats of the practical application of chemical and physical principles to the problems of chemical manufacture, together with the principles of standard types of machinery and apparatus in use in the chemical industries. Trade catalogues are used as much as possible to familiarize the students with the design and construction of the various types of apparatus.

It is rather difficult for us 100 years later to imagine what subjects these courses covered and how students could be taught from trade catalogues. Professor Mellon of the Chemistry Department notes that these catalogues could be seen in piles on the right side of Peffer's desk. Peffer was also aware of Davis' Handbook and he used it as a reference in ChE 1 and 2, according to narrations of several students of those times. In 1912 Peffer added ChE 3 and 4, Principles of Metallurgy, as required senior courses for all chemical engineers. In 1918 he decided to add physical chemistry as a required course for ChE juniors. Ernest H. Hartwig (B.S. '19, M.S. '21) describes the status of ChE education from a student's point of view[13].

> The emphasis at that time was about 90% on Chemistry and 10% on Engineering. We had a one semester lab course in Mechanical Engineering and a bit of Electrical Engineering. We were supposed to get a semester of surveying, but in the summer of 1917, the curriculum of the entire University was drastically changed and our class missed the surveying and also one semester of Biology, which I have always regretted.
>
> On the other hand, we had two semesters of General Chemistry including one lab period a week in the Freshman year. In the sophomore year we had a full year of Qualitative Analysis with lab periods in the northeast corner basement room where the fumes and smoke were often so thick, I often wonder how we survived. In the junior year we had a full year of organic and also a full year of quantitative analysis with lab periods for each. Finally, in the senior year we had advanced quantitative analysis of commercial products, metals, minerals, fertilizers, foods, oils, etc., with two lab periods a week. This also included Electro-analysis, Fire Assay and

the rudiments of Metallography. Also, as seniors we took a three-hour lecture course in Physical Chemistry.

Peffer had ambitious ideas about the education of chemical engineers, although not the funds and staff to implement them. In the 1922-23 Bulletin he writes: "The chemical engineer deals not only with chemical principles, but also with the design, construction, and control of plant in all departments. His preparation must accordingly be thorough in both chemistry and engineering." By 1922 he had added to the curriculum courses on power plants (ME 21), applied mechanics (MECH 1 and 2) and improved electrical engineering courses (EE 9 and 10). In 1922 six more ChE courses were added. ChE 3 and 4, Applied Thermochemistry and Thermophysics, dealt with fuel technology, furnace construction, producer and illuminating gases, and materials of construction. ChE 5 and 6, Principles of Metallurgy, and ChE 7, Mineralogy, were taught by P.L. Charles. Finally, it was in 1922 that M.G. Mellon started teaching ChE 8, Technical Literature, which would stay in the ChE curriculum as a required course until 1961.

In 1922 Peffer offered for the first time three options for juniors and seniors, three specialized areas of study: military, general and chemical engineering. With the addition of J.L. Bray in 1923 further changes in the curriculum were made. The new plan of study (Appendix E) emphasized engineering principles, metallurgy and chemistry. In 1923 with the introduction of a graduate program throughout the university (E.G. Mahin was the originator of the graduate program), the numbering of the courses changed. Three digits would be used henceforth, and 100-type courses were for upper-division undergraduates, whereas 200-type courses were for graduate students. ChE 101, 102, 103 and 104 were now the main courses of the School; the course of Professor Mellon was transferred to the Chemistry Department and became Chem 123, and, for the first time, PHYS 112 Pyrometry, a physics course taught by G.W. Sherman, was added to the curriculum as a required senior course.

(Left) Sara Atanasov (BS '10), ChE Coop, and (right) Brian Lowry (BS '10), ChE Honors, won the 2010 AIChE Regional paper competition and poster competition, respectively.

The Honors Program

A course, ChE 111, was established in the fall of 1925 under the title Chemical Engineering Problems and under the direction of Peffer, Bray, and Anderegg of the Chemistry Department. It was intended for "undergraduate honor students (and) provides an opportunity for original investigation on special problems in chemical engineering." Thus, ChE 111 can be considered as the nucleus of an honors program in the School; crystallization and growth took much longer.

In 1983 during Andres' administration an honors program was established by the ChE faculty and was sent to the College in 1984 for approval. The program was approved in 1984 as an alternative educational program for highly motivated seniors, particularly those interested in graduate school. Thus in 1985, the first six students participating in this program graduated with B.S. theses performed under the direction of D. Ramkrishna, G. Tsao, L. Wang and S. Ash. In 1990 there were 12 B.S. honors graduates, 20 in 1993, 28 in 1994 and 34 in 1995. Looking at the quality of some of the honors theses, the faculty decided that the requirements for the honors needed to be tightened. In spring 1994 the requirements were tightened (for next year). The new rules require a minimum GPA of 3.6/4.0, a B or better in seven core courses, plus the honors students had a more challenging lab course, a one year senior research project, and a challenging elective course. In 1996 with more stringent requirements, only 16 students did honors theses. The honors laboratory was discontinued in 2004. After the embarrassment of having one of the School's very good graduates fail a transport course in graduate school, ChE 540, Transport Phenomena, was made a required course for honors students. The Honors program continues with the changes that since both Purdue University and the College of Engineering instituted honors programs in the 2000s, the ChE honors program now meshes with these programs.

In the fall of 1926, W.B. Sanders, Assistant Professor of Applied Mechanics, started teaching, with the collaboration of Peffer and Bray, the first design course for ChE's, ChE 116 Plant Design and Layout. Here is a description of this course in the 1926-27 Bulletin.

> Application of chemical, physical and mechanical principles to design of machinery and apparatus of chemical engineering; plant layout and arrangement.

The next major additions of courses to the curriculum would occur in 1930 with the arrival of Shreve. Initially Shreve introduced several courses in the area of organic chemical technology, ChE 126 to 129, which after the death of Peffer were increased to eight courses. In the early days (before 1935) Shreve's courses were descriptive representations of current industrial processes. For example, courses ChE 126 to 129 included descriptions of "processes for the manufacture of paper, soap, glycerin, rayon, starch, paints, varnishes, lacquers, explosives, resins, celluloid, leather, insecticides, and rubber." Shreve believed[14] that the students had to have "well equipped laboratories to understand the various industrial processes." After 1935, a major change occurred in Shreve's educational philosophy. This change was the result of adapting the new ideas applied by Lovell in unit operations to Shreve's interest in organic technology. In 1935 he started presenting the idea that industrial chemistry could be classified according to a series of "unit processes" such as alkylation, nitration, oxidation and sulfonation.

Shreve wrote several articles on this subject15-20 and based his classification on older ideas put forward by German organic chemists in the 1920's. He was especially concerned with the progress of unit operations at the expense of industrial chemistry in major Schools such as M.I.T., University of Michigan and University of Wisconsin and he had considerable, and somewhat heated, discussions with the main proponent of unit operations at the School, Clifton Lovell. In a 1938 position paper, ironically entitled *Unit Operations* and corrected with pencil by Shreve to *Unit Processes*, he wrote[21]:

> Chemical engineering instruction as now practiced has in general two specific divisions: Unit Operations and Unit Processes. The distinction between these two has been to place physical procedures under Unit Operations and those involving chemical change under Unit Processes. This is a very useful, but not an ironclad, division. The study of both Unit Operations and Unit processes is essential to a thorough training in chemical engineering, in that the chemical industry is based upon both types of change.

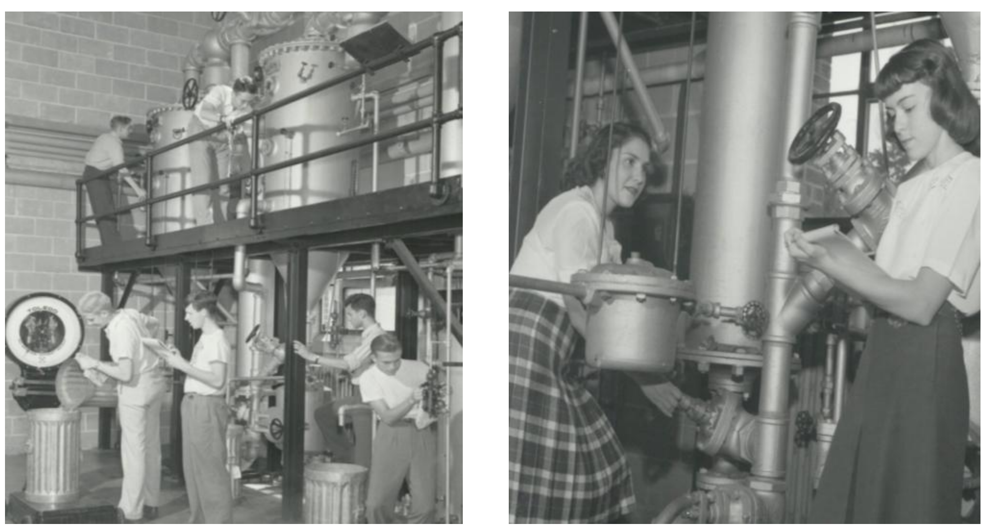
Left: John L. Bray, here shown in 1944, wrote two successful textbooks in metallurgy.
Right: Clifton L. Lovell, shown here in 1940, was the pioneer faculty members who introduced unit operations, heat and mass transfer, distillation, separations and applied mathematics courses in the undergraduate and graduate curricula.

Shreve's ideas were soon adopted by other Schools which instituted at least one course in unit processes. The subject of unit processes per se was a rather dry one, requiring an endless description of processes and operating conditions, so that even excellent lecturers, such as Shreve, could not pay justice to the subject. The older generations of ChE students recall with awe the various required courses they had to take in unit processes during their undergraduate years, courses which were facetiously baptized "Flowsheet 101" or "Making chemicals from water, earth, fire and naval stores." Memorization of flowsheets was a common requirement in these courses. Unfortunately, most unit processes courses did not delve deeply into why the process worked or how to generate alternative processes. Probably the most open critic of this educational approach was R.L. Pigford of the University of Delaware, who in 1976, wrote[4]:

> Thus, chemical engineering curricula developed before 1950 in many schools as a two-part subject with applied physics and unsophisticated

> mathematics undergirding the unit operations and with applied physical chemistry nearly the only component derived from chemistry. Although chemical engineering students studied organic chemistry alongside chemistry students, instruction in chemical engineering departments seldom was affected by inorganic and organic chemistry directly. Most students and faculty members were fascinated with the mathematical analysis of process problems, not by the invention of processes incorporating new chemistry.

Shreve wrote a well-known book in which he attempted to categorize organic and inorganic reactions into groups as had been done with the unit operations. However, the absence of quantitative, theoretical treatment made the subject seem too much like unnecessary "memory work" for most students. Thus, many graduates had to learn from their industrial practice of engineering that, without some appreciation of chemical properties and phenomena (which they could have obtained from their unit process courses), they were ill prepared to deal with some of the real industrial problems instead of the textbook problems. However, on a contrary note, Robert Hannemann, a distinguished 1952 graduate of the School and one of the first graduates to go to medical school, in 2011 rated Shreve as the professor who had the most impact on him, and noted that memorization of flow sheets was excellent preparation for the enormous amount of memorization required in medical school. But years after Hannemann graduated, Shreve routinely introduced Hannemann as a chemical engineer who went wrong.



Left: A 1941 photograph of the Unit Operations laboratory.
Right: ChE students working in the Unit Operations laboratory in the fall of 1948.

When the King believes an idea, that idea prevails. At Purdue, until he retired in 1955, Shreve was King and his ideas prevailed. After 1955 Shreve still had clout, but he was now a retired King and other curriculum ideas started to bear fruit. For years, almost until the mid 1960's, the School had the reputation as an excellent place to study industrial chemistry, but a rather mediocre place for the more modern topics of chemical engineering. Thus, in many ways Purdue was a fine springboard to an industrial career, but not nearly as good a preparation for graduate school. Although reputations linger longer than is appropriate, this one was to a large extent appropriate at least until 1960. The final nail in the coffin was adoption of the landmark 1961 curriculum (Appendix I) that did not include unit processes or metallurgy. But, we have gotten ahead of our story.

The 1935 *Bulletin of Purdue University* describes a total of 26 undergraduate and eight graduate courses. In addition to the courses discussed before, there were several courses on various aspects of metallurgy and engineering geology taught by Bray and Serviss, and two courses on gas engineering offered by Leckie. The courses offered by Bray were some of the best in the country and the School was nationally recognized for its program in metallurgy.

This was the educational direction of the School's curriculum in the fall of 1934, when Clifton L. Lovell joined the School. Lovell was an excellent educator and researcher with far-reaching insight. By today's standards, Lovell's educational contributions were monumental. He was the first to introduce unit operations, fluid mechanics, heat and mass transfer, and applied mathematics in the curriculum. It is unfortunate that his contributions were not recognized for years, and even more unfortunate that most of his writings were lost in the 1967 purge of the School's Archives. Recently, the two authors of this book had the opportunity to meet Ms. Mary Longo Cohn, a granddaughter of Professor Lovell, who visited the school in April 2011 and offered another view in the family life of this great educator and researcher who died quite young[87]…

> I only have family stories about my grandfather and his family, a completely different side of him. They were a fascinating group, 11 children of a dirt farmer's from Mississippi who all went on to work their way through college educations. How all that happened is a story in itself. My mother was very close to him, the closest of his 4 children. They took long walks together and shared a like mind, hence her own studies in chemistry at a time when women did not do such things.

To appreciate the impact of Lovell's ideas in the education of our students we can examine Table 7-1 for a list of the courses introduced by him from 1934 to 1937 and their present equivalent courses. (Courses in parentheses were deleted.)

This table shows that much of today's required undergraduate and graduate curricula developed from the pioneering courses of Lovell. In a 1985 interview, Jacob M. Geist (B.S. '40), a distinguished alumnus of the School and a member of the National Academy of Engineering, stated that in 1940 only Lovell was teaching true chemical engineering.

Table 7-1. Courses Introduced by Prof. Lovell
Courses in() are no longer offered.

Course	Introduced	Later Course(s)
ChE 140	Fall 1937	ChE 20500
ChE 137	Fall 1935	ChE 37700
ChE 138	Fall 1935	ChE 37800
ChE 139	Summer 1935	(ChE 344, then ChE 434)
ChE 140	Summer 1935	ChE 445, currently ChE 43500
ChE 227	Fall 1935	(ChE 597E, 627)
ChE 226a	Fall 1935	(ChE 622)
ChE 226b	Fall 1935	ChE 62300
ChE 226c	Fall 1935	ChE 62400 (infrequently offered)
ChE 226d	Fall 1935	(ChE 625)

In the summer of 1935, the unpopular summer session was initiated. This was a required set of two unit operations laboratory courses (ChE 139 and 140) placed between the junior and senior years. At the end of the summer of 1957 this requirement was abolished. The idea of a required summer session was not new. At the University of Wisconsin a summer course was initiated around 1930 and is still required of all juniors. The summer session in ChE was a required two-course program scheduled between the junior and the senior years. The two laboratory courses were on unit operations.

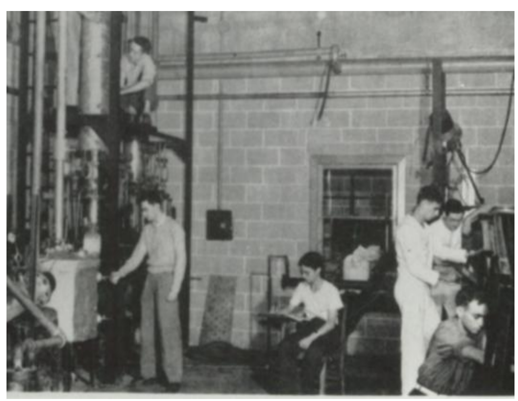
The summer session in ChE was a required two-course program scheduled between the junior and the senior years. The two laboratory courses were on unit operations.

Appendix F shows the 1936-37 plan of study. All juniors were required to select an option. Five such options were offered: general, military, gas engineering (under Leckie), metallurgical engineering (under Bray) and organic technology (under Shreve). Both Bray and Shreve were interested in the German language education of the students, although the requirement had been reduced to two courses. Both courses disappeared from the curriculum in 1941. In collaboration with Professor Fotos they wrote three textbooks on German for chemists. The Archives contain long correspondence of Shreve with industrial representatives discussing the pros and cons of the German requirement. The courses were taught by Fotos, Shreve and Bray using technical subjects submitted by the ChE professors[22]. In a memorandum of January 5, 1938, Bray wrote[23] to Shreve:

> I have had an opportunity to examine your new German Reader. You are to be congratulated on this excellent piece of work for I feel sure that it will fill a long felt hole. The subject matter is well balanced between organic, inorganic (chemistry) and metallurgy. Apparently this new method of teaching German is going to prove very successful for this year I have not had a single complaint concerning German.

When Sherman joined the School in 1937, he introduced a course on Engineering Instrumentation (ChE 155) and taught it for 23 years. From its inception the course had elements of process control as the description from the 1941-42 *Bulletin of Purdue University* shows.

> The measurement, recording, and controlling of various quantities, including pressure, temperature, flow, viscosity; applications of telemetering, electronics.

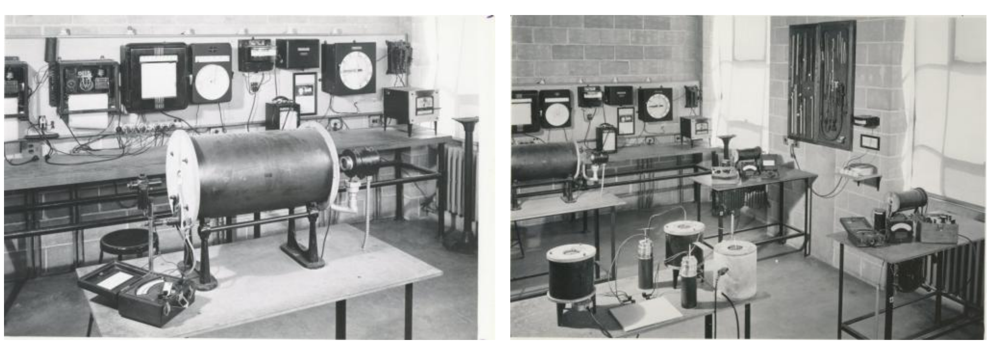


Left: Robert B. Moore, shown here in 1940, was the trusted instructor and assistant of Lovell during 1937-43.
Right: Chemical engineering students running a still in 1944.

Table 7-2. The Shreve Prize for Teaching in ChE

The Shreve Prize for Teaching in Chemical Engineering was established in 1974, when the Shreve Prize in Chemical Processing was modified to recognize outstanding teaching by a ChE faculty member. This award is given based on a vote by the seniors (seniors and juniors for the period 1974-79). Faculty members who taught fewer than 15 students are not eligible for the award. Originally, the award could not be given to the same faculty member in two consecutive years. In 2006 faculty agreed by unanimous vote for Shreve award eligibility every 3rd year. The recipient of the Shreve Prize is also the School's nominee for the A.A. Potter Award. The Shreve Prize is accompanied by a certificate and a check for $1,000, since 2007 – it had remained $500 for the previous 33 years. In general, the department has been blessed by having had numerous great teachers. As Bob Squires told one of us (NAP) when he received the first of his six Shreve Prizes in 1978 "we hire faculty members because they are great researchers and engineers. If they end up being also great teachers, we are extremely happy." The recipients since 1974 have been the following:

1974	Phillip C. Wankat
1975	Henry C. Lim
1976	Robert G. Squires
1977	Henry C. Lim
1978	Nicholas A. Peppas
1979	Phillip C. Wankat
1980	Nicholas A. Peppas
1981	Robert G. Squires
1982	Nicholas A. Peppas
1983	W. Nicholas Delgass
1984	George T. Tsao
1985	Nicholas A. Peppas
1986	W. Nicholas Delgass
1987	Robert G. Squires
1988	Lyle F. Albright
1989	W. Nicholas Delgass
1990	Robert G. Squires
1991	W. Nicholas Delgass



Two views of the pyrometry and instrumentation laboratories of George W. Sherman circa 1949.

1992	Robert G. Squires
1993	Venkat Venkatasubramanian
1994	Nicholas A. Peppas
1995	Francis J. Doyle III
1996	Robert G. Squires
1997	Francis J. Doyle III
1998	R. Neal Houze
1999	Joseph F. Pekny
2000	W. Nicholas Delgass
2001	R. Neal Houze
2002	W. Nicholas Delgass
2003	R. Neal Houze
2004	Venkat Venkatasubramanian
2005	Phillip C. Wankat
2006	Venkat Venkatsubramanian
2007	W. Nicholas Delgass
2008	R. Neal Houze
2009	Chelsey D. Baertsch
2010	Hugh W. Hillhouse
2011	Kendall T. Thomson
2012	R. Neal Houze

In 1941 Shreve, a perhaps unexpected supporter of control courses, wrote[24]:

> Every chemical process has some optimum set of conditions under which the maximum yield of useful product is obtained, with a minimum expenditure of labor and raw materials. In order to control a process exactly, the quantitative value of each of these variables should be known continuously throughout the entire cycle. Automatic recording instruments are being used widely for this purpose and to eliminate the necessity for a human operator taking the readings both during normal and abnormal conditions.

Left: R. Norris Shreve, affectionately known to the students as "Benny", liked to talk to the students about various subjects. Here he is shown at a senior picnic in October 1964.
Right: The plaque of the Shreve Prize for chemical processing (before 1974) and teaching (after 1974).

As World War II approached, Bray, Lovell, and Shreve were the three major forces in the School. Bray had concentrated on metallurgical engineering, which had become a separate entity within the School. Shreve and Lovell were in charge of the main stream ChE's and were offering an in-depth education in unit processes and organic chemical technology (Shreve), and unit operations and transfer processes (Lovell). Shreve presented an interesting analysis of his educational philosophy in an unpublished article[25] entitled "Some Observations Regarding Chemical Engineering," dated December 5, 1938, and discovered in his files in the special collections of the Purdue library. Here we reproduce major portions of it, since it sheds light on the directions Shreve thought Purdue ChE should follow in the 1930's and 1940's.

> Chemical Engineering is the youngest of the important branches of engineering. In the last twenty-five years it has evolved out of chemistry—in a somewhat similar manner as was the growth of electrical engineering out of physics at a much earlier time. Twenty-five or thirty years ago the field now covered by chemical engineering was that of applied chemistry and also, to a certain extent, mechanical engineering. In those days, the chemical changes (now recognized as unit processes) and the physical changes (now recognized as unit operations) were carried on in a rudimentary way by those who had training in the field of chemistry. In 1906, as a student at Harvard, I attended lectures by W.H. Walker in what was then called industrial chemistry but which was the start of Walker's conception of unit operations, brought to fruition in the book by Walker, Lewis and McAdams on this subject.
>
> Probably one of the quickest changes that has ever taken place in the field of applied science had been the growth of chemical engineering during this period. We really have a lusty infant that we are playing with and it seems to me that it is up to a number of us as to whether the growth takes place in a limited manner or in a broad field. We can either confine chemical engineering, as is done by a number of older men in the AIChE, and have it embrace only the physical changes, or those recognized as unit operations, or we can go to the limit and bring within the field of chemical engineering those that are dealing with the application of chemistry to industry. Such a breadth of chemical engineering would be analogous to the fields now covered in their own particular scope by electrical engineering, civil engineering or mechanical engineering. The recent tendency seems to be to broaden our engineering fields rather than to narrow them.
>
> Before we begin to examine a typical definition such as this applied to chemical engineering let us first ask what is left to chemistry. This will cover certainly the theoretical fields of inorganic, organic, analytical and physical chemistry. Indeed this is the type of teaching and research confined to such institutions as Harvard and Princeton. It is true of the teaching of chemistry here at Purdue, but it is only partly true of the research work here. Particularly under the leadership of Professor Haas much of applied chemistry has been investigated. I would say that strictly speaking some of the research, though none of the teaching, carried on in the department of chemistry really belongs within our fields, but on the other hand, Purdue is serving industry better with more and more work in the applied field, and rather than discourage any such work on the part of chemistry, I would encourage it.
>
> A broad view of chemical engineering would be to so train men that

they enter into the chemical industry able to carry out the following:

1. Design of equipment for carrying on chemical changes.

2. Supervision of equipment and men producing chemicals and allied products.

3. The research and development of new products, or the improvement of old processes. Already in the organic chemical industries there is being spent for research $4.30 from every $100 of sales.

4. The sale of chemicals. This involves in our modern chemical industry the servicing of such sales; indeed the large majority of chemical firms now refuse to hire for salesmen anyone without a technical background.

5. Executive work in chemical fields.

Here at Purdue we are apparently going to continue to have a large school, so we shall `produce' a considerable number of chemical engineers. We have to `sell' these in the prevailing market just as though we were dealing with a manufactured product. Therefore, it is particularly necessary for us to broaden the fields into which our graduates can enter. We should prepare for (1) design, (2) production, (3) research, (4) sales and (5) management. Research is a field in which I see a large potential avenue if we do not neglect our chemical aspects. How much better for developing a new process in the laboratory and carrying it through into the factory is a man trained in unit operations, unit processes, and theoretical chemistry, than one schooled in theoretical chemistry only!

NB: Reading again this statement 25 years after I wrote the first edition of this History and almost 75 years after Shreve composed it, I (NAP) cannot but lament how much we have changed… Addressing important educational and pedagogical questions is now done in laconic electronic messages (or Twitter statements?) without appropriate thinking of all consequences of major decisions that will impact the education of the next generation of chemical engineers.

During the war, a large number of students enrolled in the ChE program. War conditions led to the establishment of an accelerated program in the School, whereby a student could receive the B.S. degree in three years. In 1944 "credit hours" replaced the previously used "semester hours." Immediately after the war several new professors were hired. Their contributions to research and the School in general are discussed in Chapters 3, 4 and 8. Among them, J.M. Smith, Doody, Bennett, Myers and Comings had the greatest impact on education.

J.M. Smith, who arrived at Purdue in the fall of 1945, immediately introduced an undergraduate (ChE 10, then ChE 410) course in ChE thermodynamics. Until then, thermodynamics was covered in mechanical engineering courses taken as electives by chemical engineering students. Doody made contributions in the areas of mass transfer and distillation and in the unit operations laboratory.

Probably the most important contributors to the educational program of the School during that period were Carroll O. “C. O.“ Bennett and John E. “Jack” Myers. They made major changes in the undergraduate and particularly the graduate curricula and introduced or completely redesigned several courses still in existence today. In the undergraduate curriculum in Fall 1950 they redesigned ChE 137 (now ChE 377) and ChE 138 (now ChE 378).

The double-effect evaporator in the Unit Operations laboratory in 1951.

Myers and Bennett had developed an appreciation for the modern ideas of chemical engineering and believed that the areas of transport phenomena and applied mathematics should become the center of emphasis of the ChE curriculum. Looking back at their contributions we cannot but admire their far-reaching insight and convictions in the more fundamental aspects of ChE. Unfortunately, their bold changes were not received in the best possible way, especially by those professors involved in teaching and research in the areas of unit processes and industrial chemistry. Even some of the faculty members working in unit operations could not appreciate the importance of the new ideas introduced by Bennett and Myers. Thus, between 1955 and 1960 the School passed through the first of two very turbulent periods of its history. The administration of those years could or would not help the causes of modern chemical engineering, and the support of Shreve—now retired, mostly travelling to Taiwan, but still the senior statesman of the School—was with those promoting the older ideas.

Table 7-3. The Dean A.A. Potter Award

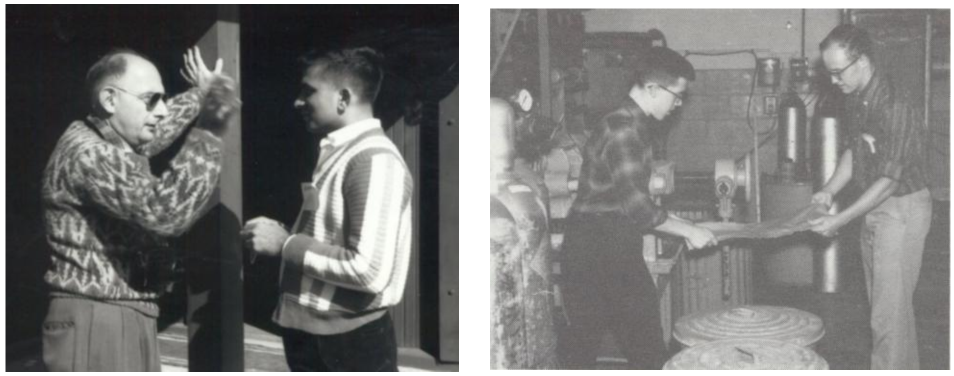
The Dean A.A. Potter Award was established in 1971 to honor the best teacher and educator in the Schools of Engineering. Faculty and students vote for this award annually. The award is accompanied by a plaque, a medal and a $3,000 check. In 1985 the Engineering Awards Committee decided that no faculty member can receive this award more than twice. This ruling was changed to once every four years in 1994 so that Dean Yang could receive his third Potter award before he left to become Vice Chancellor at UC Santa Barbara. Nicholas Peppas benefited from the change in the same year. ChE faculty members who have received this award are:

1977	Robert G. Squires
1978	Nicholas A. Peppas
1979	Phillip C. Wankat
1985	Nicholas A. Peppas
1988	Lyle F. Albright
1990	W. Nicholas Delgass
1991	Robert G. Squires
1994	Nicholas A. Peppas
1995	Francis J. Doyle
2003	R. Neal Houze

The 1950-51 undergraduate plan of study appears in Appendix G. It includes only one required sophomore ChE course (ChE 40, on heat and mass balances) and two required junior courses (ChE 137 and 138, both on unit operations). Senior required courses included thermodynamics (ChE 10), control (ChE 155) and chemical process industries (ChE 128 and 129). The two ChE laboratories appear in the summer session between the junior and the senior year.

In the fall of 1953, a new numbering system of the courses was introduced. Henceforth, courses for undergraduates would be numbered as 100 to 499, the first digit designating the student's classification (2=sophomore, 3=junior, 4=senior) and the last digit designating the semester the course was given (odd=fall, even=spring). Graduate courses would be designated as 600-level and dual-level elective courses as 500-level. Essentially, this numbering system is still in existence, except since the computer registration system accepts five digits courses are designated as, for example, ChE 30600.

The reader must note that the 1950-51 curriculum did not include courses in kinetics, reaction engineering or process design. John M. Woods, who came to Purdue in 1952, was instrumental in introducing these courses in the curriculum or redesigning existing courses to include these topics. Educated under C.C. Watson at Wisconsin, Woods believed that kinetics and reaction engineering should be an integral part of the curriculum. Although ChE 526, a dual level kinetics course, was introduced in 1953, it did not become the required senior course ChE 439 (now ChE 348) until 1963. Finally, Woods redesigned the chemical processes course ChE 529 and made it a required process design course, until ChE 450 was introduced in 1965.



Left: Alexander Sesonske (left) wrote a very successful textbook on nuclear engineering.
Right: Phillip C. Wankat (right) and fellow undergraduate Fred Mollenkopf in the Unit Operations laboratory in November 1965.

During the 1950's and early 1960's there were significant changes in courses, but no major changes of the curriculum. Many short-lived courses were introduced and dropped after a few years. These include: ChE 428 (on industrial chemical processing), ChE 525 (process design), ChE 541 (industrial chemistry), ChE 543 (chemical process laboratory), ChE 544 and 545 (nuclear engineering), ChE 560 (high pressure technology), ChE 616 (organic technology), ChE 626 (mixing), ChE 644 and 646 (nuclear engineering), ChE 617 (organic technology laboratory) and ChE 628 (advanced unit processes). These were the last efforts of some faculty members to revive unit processes and organic technology in a more modern educational environment. The effort failed, and in 1965 only two courses on the subject were left: ChE 529 and 629. These merged into one elective course in 1971, ChE 529, which is no longer offered.

Table 7-4. National Awards for Educational Excellence

Several faculty members have received national educational awards from the in recognition of their outstanding contributions in engineering education.

Phillip C. Wankat (1984) and Nicholas A. Peppas (1992) received the ASEE **George Westinghouse Award**.

Three Purdue ChE faculty members have received the **Western ElectricFund Award** of ASEE: R.G. Squires in 1977, N.A. Peppas in 1980 and P.C.Wankat in 1984. This award became the Illinois-Indiana section of ASEE **Best Teacher Award**, which was won by Francis Doyle in 1996 and R. Neal Houze in 2000.

N. A. Peppas won the **National AIChE Best Counselor Award** in 1982.

Three faculty members have won the **ASEE Chemical Engineering Division Lectureship Award**: Lowell B. Koppel in 1982, Rex Reklaitis in 1994 and Phil Wankat in 1997. In addition, Joe Smith won in 1970 while at the University of California at Davis, Arvind Varma won in 2000 while at Notre Dame, Nicholas Peppas won in 2006 while at the University of Texas at Austin, Jennifer Sinclair Curtis won in 2008 while at the University of Florida, and Frank Doyle in 2010 while at UC Santa Barbara. In addition, former Purdue ChE students won it: Bob Reid (MS '54) of MIT in 1977 and Tony Mikos (PhD '88) of Rice University in 2009.

P.C. Wankat won the **Dow Outstanding Young Faculty Award** of ASEE in 1980.

Rex Reklaitis and Robert Squires received the 1991 **Corcoran Award** for the best paper in *Chemical Engineering Education*.

R. Neal Houze won the ASEE **Alvah K. Borman Award** (1989) and the ASEE C**lement J. Freund Award** (1990) for contributions to co-op education.

Jennifer Sinclair won the ASEE **Sharon Keillor Award for Women in Engineering Education** 2003 and alumna Julie (Myers) Ross (BSChE '90) won in 2007.

The ChE Division of ASEE **Lifetime Achievement in Chemical Engineering Pedagogical Scholarship Award** to Phil Wankat in 2004.

Phil Wankat co-authored a paper with Kenneth P. Brannan that won the **Best Conference Paper Award** at the ASEE Annual Conference, Portland, Oregon, 2005.

The ChED **Martin Award** for best paper at ASEE Annual Conference to Phil Wankat in 2009 and to alumnus Alex Scranton (Ph.D. '88) in 2000.

Robert Squires in 1985 and Phil Wankat in 1993 won the **Chemical Manufacturer's Association Catalyst Award.**

The ASEE **Carlson Award** was won by Phil Wankat in 1990 and by Robert Squires in 1995.

Alumnus Tony Mikos (PhD '88) received the ASEE **Meriam/Wiley award** for best textbook of the year in 2010 for his "Biomaterials: The Intersection of Biology and Materials Science."

Nuclear engineering became an entity within chemical engineering in 1956 when Alexander Sesonske started teaching dual level courses in this area (ChE 544 and ChE 545). In 1967 he wrote his classic text Nuclear Reactor Engineering. These courses disappeared from the curriculum in 1970 when Sesonske moved to the School of Nuclear Engineering.

Polymer science and engineering was the other area that became popular in the 1950's. Brage Golding introduced the dual level course ChE 542 in the fall of 1955 while still a Visiting Professor, and taught the course with Lyle Albright, L.C. Case, and Roger Eckert until he departed in 1966. His book Polymers and Resins was an effort to merge ideas from organic chemical technology with the more modern notions of polymers. ChE 542 remained a course predominantly addressing polymerization reactions and processes until the course was changed significantly in 1977. It is now taught as a very popular undergraduate elective, ChE 44200.

In 1959 another major change occurred in the educational program. That year the Cooperative Education Program in ChE was established with W. Henry Tucker as its first coordinator. Students participating in this program take five years to graduate including four semesters (with summer sessions) of industrial experience. The first three Co-op students graduated in 1963. Cooperative education is unique in that it is the only major educational innovation that can clearly trace its origins to engineering—it was invented at the University of Cincinnati. The Co-op program was discussed in more detail in Chapter 4.

The COOP program has waxed and waned since 1959, but it always provides a superior education. 2009 COOP Students in front of the Engineering fountain.

Coop student Holly Huseman on the job with SABIC Innovative Plastics in Mt. Vernon, IN.

3rd Annual Women in ChE Seminar – March 26, 2011. ChE has been a leader in welcoming women into engineering.

Comparing the 1961 class photo (Left) to the 2009 class photo (below), our progress in increasing diversity in chemical engineering is evident, but more work is required particularly to attract and retain underrepresented minorities.

Students from Groups Underrepresented in Engineering

By the 1970's it was clear that, despite the presence of a few pioneering women and students from minority groups, the reason engineering in the US had very few female or minority students was partially due to *us*. For example, until one of Purdue's brave female undergraduates complained loudly to the administration, there was only one women's rest room in CMET. Fortunately, once the Purdue College of Engineering realized there were difficulties, prompt actions were taken. The Women in Engineering Program (WIEP) at Purdue, the first in the country, was founded in 1969 and has served as a model for the rest of the country. In fall 2010 enrollment of undergraduate women in the College of Engineering was 19.8% and over the last decade 19.1% of the graduates are women. Chemical Engineering is higher than this and in August 2010, 31.6% (down from the peak of 40.0% in spring 1999) of the undergraduates and 25.9% of the graduate students were women (compared to 20.0% for the College). Purdue has a very strong student chapter of the Society of Women Engineers (SWE), and two of the national presidents of SWE are graduates of the School—Roberta Banaszak Gleiter who was president in 1998-99 and Ronna F. Robertson who was president in 2005-06.

The Minority Engineering Program (MEP) was founded in 1974 and its focus is domestic underrepresented minorities from African American, Native American, Mexican American, and Puerto-Rican American groups. Purdue was the founding site of the National Society of Black Engineers (NSBE) in 1974. The enrollment of underrepresented minorities in ChE in August 2011 was 1.9% African American, 3.7% Hispanic and 0.8% American Indian for a total of 6.4% (down from the 8.3% in fall 1997, but up from 4.2% in fall 2004) underrepresented undergraduates and 0.9% for graduate students.

In 1996 ChE, led by Caruthers, started a ChE Minority Scholars Program to increase the number of minority students graduating from the School. This program included a summer program with the students paid a salary of $2000 per month. Unfortunately, there was considerable difficulty obtaining enough participation from students who had completed the Freshman Engineering Program, and eventually the program was dropped.

Campus climate is important to underrepresented minority students and recruits often ask if the campus is friendly for women and minority students. Professor Harris, whose current duties as Associate Dean include oversight of the WIEP and MEP programs, states "'Although Purdue is struggling in minority recruitment, students who come here trust our program because they have the faculty and peer mentors and the organizations to support their work.' Beaudoin, a member of a university-wide diversity task force, is aware that issues of race, gender, and ethnicity have negatively impacted students on campus, but believes that students in Chemical Engineering feel at home and those incidences are rare. In fact, Beaudoin and Harris say that students in the school work well with their peers to complete common goals—with the mentality that everyone is a Purdue student and colleague, regardless of background. Expectations among students, Beaudoin says, are based on formed relationships, not on status. 'Having an attitude of acceptance and appreciation for all backgrounds is a vital component to the success of our students in their careers,' he says. 'Many minority students come here with an expectation that Purdue won't be welcoming, and our goal is to partner with the students and change that perception. I think we're succeeding.' Talesha Hall, a graduate student in Chemical Engineering with a prestigious NSF fellowship, came here from Baltimore because of the faculty and research. 'After several visits, I felt the most comfortable about Purdue,' she says. 'During my time at Purdue, I've been able to get through difficult challenges with the help of my classmates. I also had some difficulty deciding if I wanted to continue on the PhD track. Professors Mike Harris and Steve Beaudoin were instrumental in keeping me on board. She adds, 'I would tell potential students that Purdue's chemical engineering program is very challenging, but the education and experience you receive is second to none.'" (Quoted from Lee Lamb[26])

Increasing the number of underrepresented minorities in the graduate program is widely supported by the ChE faculty and 35% joined the Alliances For Graduate Education and the Professoriate (AGEP) program.[27] AGEP professors agree to recruit, mentor, and graduate at least one minority PhD student in a 10 year period and to help the School with its diversity objectives. Despite this effort, in 2010 there was only one underrepresented minority graduate student in ChE and in fall 2011 there were two.

The School has had a number of industrial grants[27] to develop programs to attract both undergraduate and graduate students from groups that were underrepresented in engineering. As noted above, the School's percentage women of both undergraduate and graduate students are above the all engineering averages, but we want to push this higher. Obviously, more work is required particularly to attract and retain underrepresented minorities.

In the fall of 1964 a new plan of study appeared (Appendix H). Over the years many modern courses had appeared in the catalogues. However, these courses had not been taught regularly. Compared to the 1950-51 plan of study (Appendix G) the 1964 plan reduced the number of credit hours from the ~166 in 1950-51 to 144 and the unpopular summer session was eliminated. The laboratories were moved to the sixth and seventh semesters. The chemical process industry courses were eliminated as were the metallurgy, heat treating and surveying or welding courses. This also was the period when ChE 439 and 450 were introduced as required courses in the undergraduate curriculum. Also by 1964 Coughanowr and Koppel had modernized Sherman's course (ChE 155, then 455) and offered it as a required senior course (ChE 456). The plan of study in Appendix H is clearly a modern chemical engineering curriculum, although the credit hours were still a bit high.

Changes between 1964 and 1977 included the revamping of several courses, such as transport phenomena (by Greenkorn and Kessler), thermodynamics (by Chao, Greenkorn and Squires), kinetics and catalysis (by Delgass and Squires), separation (by Wankat), statistics (by Eckert), mathematics, optimization and control (by Reklaitis, Lim and Weigand), and biochemical and environmental engineering (by Lim and Tsao). The educational philosophy and changes of the courses have been presented in a large number of articles[28-44] by the faculty. We note that revamping courses is similar to remodeling kitchens—every seven or so years it needs to be done if one wants to have a modern kitchen (or course). From the point of view of the students the biggest change in these years was the removal of required courses in military training, statics, modern physics, two courses in electrical engineering including one on vacuum tubes, professional guidance and inspection trips (really great fun!), and materials (MSE 411). In some cases these courses were replaced with electives and in other cases the credit hours required for graduation were reduced to close to the 131 required in the 1981 plan of study (Appendix I). This is very close to the current requirement of 130 credit hours (Appendix K).

In 1975 a dual degree program with the Chemistry department was developed[45]. The 150 credit program was originally supposed to be done in four years. Both ChE and Chemistry soon realized that the only students who could do the program in four years were students who brought in a large number of advanced placement credits. The dual degree program is now listed as a five year program (Appendix L). The pharmaceutical industry in particular is interested in graduates from this program because the additional chemistry is helpful in that industry.

The arrival of new faculty members after 1974 led to a major reexamination of the undergraduate and dual level transport courses. This led to a change of the educational philosophy of the curriculum towards more fundamental representations. The changes undertaken by Caruthers, Houze, Kessler, Lim, Peppas, Ramkrishna and Wang are shown below.

Table 7-5. Course Design in Late 70's and Early 80's

Course	Introduced Area (i) or Redesigned (ii)	Faculty Responsible for Reorganization
ChE 377	Fall 81 (ii) transport	C,H,K,R,W
ChE 378	Fall 81 (ii) transport	C,H,K,P,W
ChE 540	Fall 81 (ii) transport	C,H,K,W
ChE 543	Fall 79 (i) polymers	P
ChE 544	Spring 78 (i) polymers	C,P
ChE 597N	Spring 81(i) transport, polymers	P
ChE 597R	Spring 79(ii) porous media	G

*C=Caruthers,G=Greenkorn,H=Houze,K=Kessler,P=Peppas,R=Ramkrishna,W= Wang.

Left: Robert G. Squires, shown here in 1976, made significant contributions in the teaching of thermodynamics and kinetics. **Right:** Steve Beaudoin (shown at 2010 graduation) has been heavily involved in recruiting and teaching undergraduate students.

An important component of large lecture courses is the teaching assistant (TA). Before 1980 graduate students who entered as teaching assistants remained TAs until they graduated. In 1980 TA duties were distributed among all graduate students[46]. Currently, all graduate students, regardless of the funding source, are required to be a TA[47] every other year. For many years the University provided TA training at the beginning of the fall semester through CETA and/or the Center for Instructional Excellence. Additional training in the form of a Classroom Climate Workshop involving role plays of classroom situations was available from 1995-1999 based on an Alfred P. Sloan Foundation Grant. Starting in spring 2009 all TAs in ChE take a teaching course ChE 697 at the same time they are a teaching assistant (see text box for Core Graduate Courses). The School awards outstanding teaching assistants for lecture style courses with the Estus H. and Vashti L. Magoon Award. This award is administered by the College of Engineering and is supported by a trust Mrs. Magoon established in 1976. In March 1988 the Dow Chemical Company provided a grant to give an Outstanding Laboratory Teaching Assistant Award. Although this award is no longer sponsored by Dow, it is still given annually. The winners are based on voting done by the undergraduate students. The Graduate Student Outstanding Service Award was established by the University in 2009. The Table in the box lists the award winners for the years that records were available. In addition to the awards on the table, in 2002 Alvin Chen won Purdue Student Engineering Foundation Outstanding Graduate Student Award; in 2003 Scott McClellan was honored at the CETA banquet for outstanding teaching contributions and Rajan Agarwal received a Graduate Teacher Certificate for completing the Preparing Future Faculty program; in 2010 Intan Hamdan won the CETA Teaching award and the Purdue Student Engineering Foundation Outstanding Graduate Student Award.

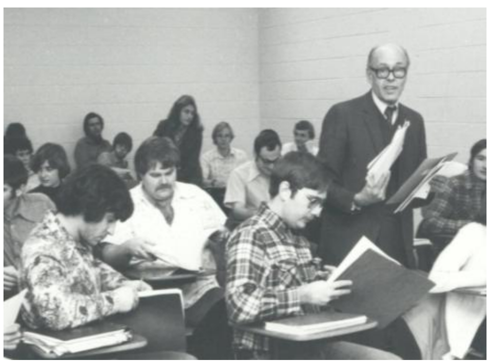
Graduate students are encouraged to pursue academic careers. One approach is to train Ph.D. students how to teach through ChE 685 and ChE 697 (discussed in detail later). Another approach is to team teach a few courses with selected Ph.D. students[48]. In Spring 2011, we conducted an experiment by having two of our outstanding PhD students co-teach ChE 320, sophomore-level course on Statistical Modeling, on their own - Santosh Appathurai and Krishnaraj Sambath. They received lecture notes and guidance from Mike Harris, who has taught the course many times. The students did a great job of teaching and, from the viewpoint of both the teachers and the class, the experiment was a success. We plan to provide more such opportunities to other students in the future. A third approach is to include graduate students in the other tasks done by professors through a Future Faculty Program. To assist graduate students plan for academic careers, Ramkrishna and Varma started a Future Faculty program in Spring 2007. Several times a semester graduate students and postdocs interested in academic careers met with different faculty members who described specific aspects of being a faculty member. Topics such as applying for academic positions including the research and teaching statements, expectations of faculty in teaching-oriented versus research-oriented departments, desirability of postdoctoral positions and how to obtain them were discussed. In 2010-11 Litster and graduate student Santosh Appathurai organized meetings. Typically, 15-20 students and postdocs attend. Additionally, almost all graduate students write and present their research results at national and international meetings.

Table 7-6. Teaching Assistant Awards

Year	Magoon Award Winners	Outstanding Lab TA Winner	Outstanding Service Award
1985	Len Kosinski Peter Nowobilski		
1987	Jeff Chou Fred Gibson		
1989	Alex Alexopoulos Donna Nugent Stevenson	Margaret Janusz	
1990	Dan Stark Abderaouff Klibi	Mark Martin	
1992	William Mahoney Faisal Siddiqui	Constance Campbell	
1993	Robert Adams John Kerney	Michael Lorenz	
1994	Jerry McGinnis Philip Wisnewski	Kristi Bell	
1995	Ron Crane Steven Honkomp	Steve Brazel	
1996	Steven Honkomp Jeffrey Varner	Theodore Pirog	
1997	Michael Buss Mark Byrne Jeffrey Varner Chris Williams		
1998	Karen Greene Praveen Gunaseelan Steven Honkomp Steven Richter William Walters	Timothy Pletcher	
1999	Praveen Gunaseelan Jay Panditaratne William Walters Jing Zhang		

2000	Shantanu Bose Nick Jones Eric Stangland Madeline Torres-Lugo		
2001	Mark Byrne Paul Fanson Ericka Hernandez Dharmashankar Subramanian		
2002	Kimberly Hayden Jennifer Lopez Jon Shepler Vijayanand Subramanian Camilo Zapata		
2003	Rob Collins Jeff Klostermann Scott McClellan David Wells		
2004	Lasitha Cumaranatunge Kyungjae Jeong Eric Sherer Ronald Suryo		
2005	none		
2006	Nanette Boyle Hak Koon Yeoh	Soon Kay Teoh	
2007	none	Peter Erri	
2008	Dave Balachandran Dana Gary Intan Hamdan Bum Soo Kim Rugved Pathare	Intan Hamdan	
2009	Intan Hamdan Megan Kelchner Rugved Pathare	Bri-Mathias Hodge	Krista Novstrup
2010	Clancy Kadrmas Kathyrn M. Smith	Easa Ismail Al-Musleh	Heather Emady Julie Renner
2011	Gautam Yadav Patrick McGough	Patrick McGough	Santosh Appathurai Sara Yohe

Changes in the curriculum during the fifteen year period after 1981 were mainly in the supporting science and mathematics courses. Comparison of the 1984 curriculum (Appendix I) to the 1996 curriculum (Appendix J) shows no change in the number of credits for graduation, and the math sequence was changed by dropping the combined linear algebra and DEQ course (MA 262) and replacing it with two separate courses, MA 265 and MA 266. The physical chemistry courses, CHM 373 and 374, were replaced with a single combined p-chem course, CHM 370, which removed much of the thermodynamics and kinetics overlap with ChE courses. In the senior year ChE 430, Principles of Molecular Engineering, effectively replaced the removed credits of p-chem and focused on solids. The other changes were addition of IE 343, Engineering Economics, increased credits in the ChE Statistical Modeling and Quality Enhancement course from 2 to 3 as the course was renamed and renumbered ChE 320, and renumbering ChE 211 to ChE 311. For a fifteen year period, there is fine tuning, not a significant amount of change.



Classrooms have been modernized in the new Forney addition.
Left: Professor Albright returning papers in 1976.
Right: Professor Reklaitis teaching in Forney Hall G124 (one of the smaller classrooms).

Undergraduate Enrollment

Enrollments and number of B.S. degrees awarded yearly oscillate both at Purdue (see Appendix M) and nationwide on approximately a 13 year cycle[49]. For many years Purdue was the number one producer of B.S. graduates in chemical engineering in the U.S.A.

In the early 1980's when enrollment became quite high (the peak in 1982 was 565 students enrolled) the faculty decided that the School's goal was to be the best, not the largest, undergraduate program. After some steps were taken to control enrollment, several programs temporarily passed Purdue in number of B.S. graduates, but by 1987 Purdue with 104 graduates again became number 1 in B.S. graduates. The number of graduates plummeted to a low of 73 graduates in 1988. Although Purdue ChE goes through the same enrollment cycles as other ChE programs, we often appear to start the downturn a year later than most programs and start the upturn two or three years earlier. The result is that even with enrollment caps during the peak periods, the School produces more B.S. graduates during large parts of the cycle. For example, 1990 or 1991 was the low in B.S. graduates for most programs[49], but Purdue was clearly on the upswing in 1989 and our 92 graduates was the second highest in the U.S. In 1990 and 1991 when most programs bottomed out, Purdue had increased 48% and 75% from the low to reach 108 and 128 graduates, respectively. The 1990 and 1991 totals were both the highest in the U.S. Clearly, Purdue roared out of the enrollment recession faster than other schools. In January 1994 an incredible 676 students were enrolled in ChE. Since the School was unable to find places in the laboratory courses for all the students, the senior lab was offered in the summer of 1993. In fall 1994 an enrollment cap was put in place by requiring students leaving Freshman Engineering to have a 2.9 or higher GPA to enroll in ChE. The graduating class was 170 in 1993-94, 185 in 94-95, 186 in 95-96, 184 in 96-97, and 150 in 97-98 as the enrollment cap kept enrollments from rocketing even higher. When the School had its accreditation visit from ABET (Accreditation Board for Engineering and Technology) in fall 1995, we received a complete accreditation for six years, but the major advice was to reduce the student/faculty ratio. The mechanism to do this (the enrollment cap) was already in place by time we received this advice. By fall 1997 total enrollment in the School was down to 430, a much more manageable number. A few universities that did not cap enrollment passed Purdue in number of graduates by 1996, but for the entire decade Purdue produced the largest number of ChE graduates. The large national production of graduates eventually wreaked havoc with the job market. Only the co-op education students could count on obtaining a job by the middle of the decade.

This entire scenario repeated again in the 2000's with a minimum national production of BS graduates in 2005-06 of 4452 (for comparison, it was 6023 in 1999-2000). Purdue graduated 91 students in 2005-06 (tied for 4th in US) and 93 graduates in 2006-07 (tied for 4th again). In 2007-08 the number of Purdue graduates plummeted to 76 (tied for 10th), but then rebounded in 2008-09 to 2nd with 106 graduates (Michigan was 1st with 113 graduates). The peak enrollment and peak production of BS graduates will probably occur around 2011-12. Unfortunately for the graduates, there is the added difficulty of a recession and slow recovery of the job market at the same time the number of graduates is increasing. The good news is that at this time (May 2011) the job market appears to be opening up.

Huge enrollments strain facilities and people. Most course, laboratory and curriculum innovations occur when enrollment is modest because that is when people have the time to try something new. The late 1980's were a period of curriculum and course innovations. Options for advising students in choosing electives were developed. Squires and Reklaitis obtained grants for computer simulation of laboratory projects from Mobil, Eastman Kodak, and Air Products. A 1992 proposal resulted in a $1.0M grant from Dow over five years starting in 1993 to implement the Dow Chemical Engineering Instrumentation Laboratory. Caruthers obtained money from the GE Foundation to develop an engineering-wide design course with modern materials and later money from the Dean to develop lecture-demonstrations. This project eventually became the Fundamentals laboratories which were started in the next enrollment trough but completed as enrollments shot up. Developments in the late 1980's and early 90's included a new course on modern polymeric and electronic materials, an expanded required statistics course, renovation of the undergraduate laboratories, more emphasis on report writing and oral presentations in senior lab, and writing of textbooks. In the early 1990's the faculty adopted a student mentoring system to focus on educational and career counseling, not registration, with each professor following 20-25 students from sophomore to senior (see box on Academic Advising). By the mid-1990's the amount of innovative educational projects had decreased.

Perhaps because enrollments were low in the mid to late 80's and energy was not siphoned away into curriculum innovations, the elective educational program of the 1980's and 1990's was one of the richest in the country. Elective courses covered a wide range of subjects from biochemical engineering to semiconductors and from optimization to colloid and surface science. A series of concentrations or options were developed to help students choose electives. Originally[50], the concentrations included biochemical, biomedical, catalysis and reactor engineering, chemical engineering science, chemical industry management, environmental, materials processing, polymer science and engineering and process systems engineering. This number of concentrations proved unworkable, particularly since some had only one professor available to teach courses. Currently, the School has reduced this to four concentrations—energy and environment, materials and polymers, biological engineering and pharmaceutical engineering. Students are not required to choose a concentration—they can pick whatever electives are available that sound interesting. All of the concentrations require nine credits of electives of which at least three credits must be a ChE elective. Ideally, two courses that count as ChE electives would be available every year for every concentration. Unfortunately, with the current curriculum challenge from the dean to decrease teaching loads for research active faculty to one course per semester (the reason is to increase research productivity and other types of impact) it will be very difficult to keep the current four undergraduate concentrations, and have sufficient graduate electives (both 500 and 600 level). Graduate level electives are already on two or three year rotations. A two year rotation for undergraduate elective courses will mean that some students will not have the option of taking the elective course if a second semester junior course or a first semester senior course is a prerequisite. As of fall 2011, faculty discussion about the concentrations is continuing.

ChE students in ChE 320 lecture
in Forney G140 in spring 2011.

Behind the scenes, throughout the 1990's Elias Franses and Wayne Muench led an effort to substantially renovate and re-equip the senior ChE laboratory. Originally planned to last a period of three years, it took about three times as long. Subsequent goals include the development of laboratory facilities to support the core junior year courses—a project that eventually became the Fundamentals Labs that are discussed in detail later. The comprehensive senior lab revitalization project is the type of effort needed periodically to keep an instructional laboratory in good shape. We are now again at a point where major revisions of the senior lab need to be planned – this is a good time as renovation of CMET building is near completion and funds can now be raised to upgrade the senior lab.

Another behind the scenes effort from the late 80's until the late 90's were continual efforts to upgrade the School's computer facilities from abysmal to pretty good. In the late 80's the Dean of Engineering, Henry Yang, was very much in favor of having the Schools upgrade their computer facilities. To encourage this he would periodically provide matching funds for computer upgrades. Money from New Directions and the Dean was first used to remove dumb terminals and replace them with personal computers and work stations. In 1992 new computer facilities from a joint Lubrizol-HP grant was put into place. The Dean's allocations continued until he left Purdue in 1994. A few years later the University approved a student differential fee for engineering students to provide money for the Schools of Engineering to purchase the expensive equipment needed to educate engineering students. In 1987 Prof. Pekny and Steve Plite, the computer director for the School, developed a successful proposal to use some of the funds obtained from the student differential fee to purchase computers for student use. Of course, buying new computers is a never ending task, but it has gotten easier as the price of computers has dropped. In addition, most students now have their own personal computers, which reduce the load on the departmental computers for routine tasks such as word processing.

Academic Advising of Undergraduates

Ideally, academic advising of undergraduates will go hand in hand with the curriculum to help students optimize their time at the University. 80% of universities advising is done by faculty51. For a number of reasons (no training, no role models, confusion over whether advising is teaching or service, personalities, lack of time, ever changing rules and course offerings), the reality of academic advising by faculty is a long way from the ideal state. An alternative is to use professional advisors, but unless they are socialized in the discipline, they cannot mentor students in becoming professionals.[51] Another alternative used by some schools is to assign all advising to one professor who then takes the time to become familiar with all the rules and course offerings, and with the changes that occur every year. At the start, the Head was the only faculty member and he did the advising. Since the curriculum had little flexibility, there were few questions about courses to take. During the later years of Bray's headship and throughout that of Shreve, Helen Wilson Giese took over the task of advising the undergraduates (and many other tasks). In December 1960 Mary Hutchings was hired to be the first administrative assistant to focus on the care of undergraduates (advising, registration, and unofficially a lot of mothering). When Mary got ready to retire in 1981, there was a seamless transition to Katie Eckman who continued in the same role.

During the period from 1960 to the mid-1980's students were assigned professors as advisors and had to see the professors to have registration cards signed. In 1977 a new scheme was tried with "Sophomore specialists" (Wankat, Delgass, Caruthers and Reklaitis), "Junior specialists"(Squires, Albright, Lim, and Chao) and "coop specialists" (Eckert, Houze, Ramkrishna and Weigand). All seniors were advised by the Head, Koppel. By 1982 it became clear this was not working and professors were then assigned to stay with a class until they graduated. Faculty still signed registration cards, but Katie Eckman provided advisors with academic registration information. After a few more years, it became clear that most professors were not familiar with registration rules, and in effect they were sending the students to Katie before rubber stamping her recommendations. So the next effort was to have Katie do the advising with mentoring by faculty. When Katie became clear that retirement was imminent, Janet Siebenthal, a professional counselor employed by Freshman Engineering, was hired. The same procedure of registration in the undergraduate office and mentoring by faculty was followed. Unfortunately, despite several different efforts (including free pizza), this mentoring procedure never worked well. The students who most needed to talk to a professor about career plans (or the lack of such plans) never took the time.

Currently, Veronica Schirm with the assistance of Sandy Hendryx provides undergraduate academic advising. The latest wrinkle in the mentoring program, started in 2009 looks as if it is working reasonably well. Students enrolled in ChE 200 are divided equally among the faculty who are not on leave. Visits of sophomores with their faculty mentor are encouraged but not required. Mentor meetings and the mentor's signature are required for juniors in ChE 300. This requirement at least gets students to sit down with a faculty member to discuss career plans.

ChE 400, the zero credit *Professional Guidance* seminar, has been increased to one credit under the direction of Mrs. Linda Davis. This picture shows ChE graduates, William J. Padgett (BS '78), Thomas C. Padgett ('78), Teri L. (Nagel) Carter (BS '81), Carol A. (Saunders) Harbaugh, and Stephen J. Padgett (BS '78) presenting their experiences of industrial practice in November 1985. [The Padgetts are brothers.]

Over the next 15 years the undergraduate curriculum shows some significant changes, plus two cases of two steps forward and two steps back. In 2002 the School followed the lead of other Schools in the College of Engineering and instituted a graduation requirement that students had to have a graduation index in ChE core courses of at least a 2.00 (the long-standing University requirement of a GPA > 2.00 refers to all courses). The proposed 2011 curriculum (Appendix K) that is effective for seniors graduating in 2012 was altered in fall 2010 based partly on the Dean's Curriculum Challenge (see box). This curriculum has Fundamental Laboratories in three of the main core courses, ChE 37700 (fluids), 37800 (heat & mass transfer), and 34800 (kinetics & reactor design). To accommodate the extra work in these labs the courses were increased to 4 credits. The first laboratory course ChE 43400 was considered to be close to redundant and was combined with ChE 43500 to form a four credit ChE 43500. Overall, the amount of laboratory experience in the curriculum remained approximately constant. An extra credit was added to ChE 20500 and 21100 to provide time for two-hour recitations. The seminar sequence (ChE 20000-30000-40000) received one credit, which was popular with the students and provided time to assess professional outcomes for ABET (see below). IE 34300 was dropped and one credit has been added to the senior design course, ChE 45000 to cover engineering economics and safety. ChE 33000 was made an elective instead of being required. In 2005 the math sequence was changed to consist of MA 26200 plus MA 30300 (Differential Equations for Engineering and Science) instead of MA 26500 and 26600. Regardless of what math sequence is used, students never seem to have the facility with math that engineering professors would like to see. A cell biology course was also added to the plan of study since biology is now considered to be a necessary science for chemical engineers. In a separate college-wide effort the first year engineering program was simplified because of concerns about retention. The net result of these changes was a one credit reduction in the credits required for graduation.

Dean's Curriculum Challenge

In August 2010 Dean Leah Jamieson presented a Curriculum Challenge to the College of Engineering[52]. Despite continuing budget reductions the College remained committed to going to the "Next Level" in innovation, strategic global partnerships, research and education. The Dean noted "Our single most valuable resource is faculty time." New roles of faculty and the way faculty time is used need to be considered. The focus of the Curriculum Challenge was to examine how resources, including faculty time, are expended in the curriculum. Within the constraint of continuing to provide a world-class education, each school in the college was requested to determine how to increase the time available for research.

Factors to consider included (but were not restricted to):

- Reducing teaching loads for faculty to one course per semester.
- Number and frequency of course offerings
- Course structures, credits, and delivery methods
- Reducing course and topic redundancy
- Pedagogies and delivery methods including use of technology
- High versus low touch including experiential education
- Roles of faculty, students and staff in teaching
- Making boundaries between disciplines and universities more permeable
- Alternate ways to provide credit, particularly for students off-campus
- Developing graduate students as future faculty
- Developing current faculty by informing them of latest finding in pedagogy.

Dean Jamieson, Dean College of Engineering (2006, to present), a noted engineering educator and NAE member.

The response of the School of Chemical Engineering was to

- Eliminate the proposed ChE 449 (three credits) but make ChE 450 four credits from the proposed two credits.
- Convert graduate core course ChE 621 into an elective (this was happening even without the curriculum challenge).
- Convert undergraduate core course ChE 330 into an elective.
- Increase flexibility in the undergraduate curriculum by changing some required mathematics courses to electives.
- Reduce the frequency of offerings of electives and require a minimum of eight students to register for an elective for it to be offered.
- Since teaching loads for research active faculty were already at one per semester, develop a "research semester" every three years. Faculty would not teach during this semester.
- Since the School already had courses to help develop future faculty (ChE 685 and ChE 697), no change was made in this area.

In reading over the Dean's memo it is notable that how professors spend time in research and engagement (aka service) were not subject to the same scrutiny as time spent in education. Faculty can spend their research time on activities that are likely to have high impact or they can spend it in areas that are significantly less likely to have impact. In addition, some professors are considerably less efficient than others in doing research and engagement.


Left: Frank S. Oreovicz (middle) made significant contributions to the undergraduate program as a guardian of good English and style in the lab and design courses. He is shown here standing between Betty C. Harvey, administrative assistant to the Head, and Ronald P. Andres, the Head of the School.
Right: Wayne Muench directed the unit operations laboratory for a number of years.

Another major educational change that is not immediately evident from the plans of study are changes in accreditation requirements from ABET, the former Accreditation Board for Engineering and Technology. The School has been continuously accredited since 1933; first by Engineers Council for Professional Development (ECPD) the predecessor of ABET and then by ABET. Accreditation assures that the program meets certain critical standards, allows graduates to sit for the Fundamentals of Engineering examination (formerly the EIT) and eventually become professional engineers. After 2000 all accredited engineering programs must meet the new standards set by ABET 2000[53]. Each program in conjunction with stakeholders (the IAC and alumni) must set program objectives (what graduates are expected to accomplish several years after graduation) and program outcomes (what students are able to do the day they graduate) that ensure the objectives will be met. Periodically, the objectives and outcomes are revisited and revised if necessary.

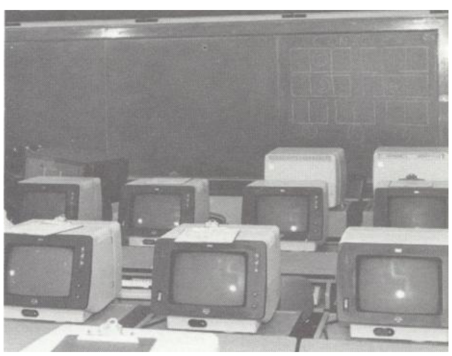
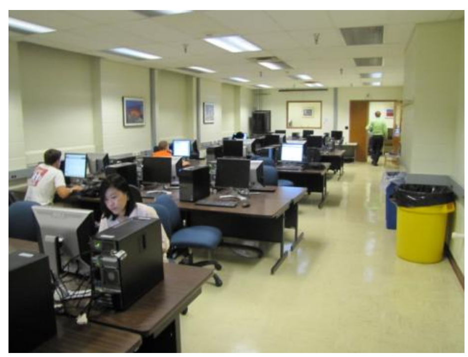
The School's current objectives are: "Within 5 years of graduating from the School of Chemical Engineering, our graduates are expected to achieve one or more of the following milestones:

1. *Advance professionally in positions of increasing leadership responsibilities within the graduate's chosen career field.*
2. *Earn an advanced degree or an advanced certification in an engineering, business, or technical field.*
3. *Engage in educational, business, or technical activities with global or socially responsible implications.*
4. *Publish scholarly article(s), file patent application(s), or present technical, professional or business seminars."*

The School's outcomes, which must embrace eleven outcomes set by ABET, are "our graduates will:

5. *be able to apply mathematics, science, and engineering principles to solve a wide range of open-ended chemical engineering problems using critical thinking and creative problem solving;*
6. *be able to design and conduct experiments, analyze and interpret data, and apply the results to chemical systems and processes;*
7. *be able to design a system, component, or process to meet desired technical, economic, safety, and environmental criteria;*
8. *be able to cooperate successfully as a member of a productive team by using their awareness of leadership and group dynamics issues;*
9. *be able to utilize the techniques, analytical skills, and modern computational tools necessary for successful chemical engineering practice;*
10. *understand and appreciate the need for professional integrity and ethical decision making in the professional practice of chemical engineering;*
11. *demonstrate their knowledge by presenting information in a logical, interesting way in both oral and written forms;*
12. *demonstrate an understanding of contemporary issues encountered in the professional practice of chemical engineering including business practices, environmental, health, and safety issues and other public interests. Our graduates will be aware of the wide-reaching effects that engineering decisions have on society, our global community and our natural environment; and*
13. *appreciate the need for and engage in life-long learning to maintain and enhance the professional practice of chemical engineering."*

For an accreditation visit, the School must prove to ABET that graduates are meeting the objectives and students are meeting the outcomes. Graduates are surveyed periodically to assess how well they are doing meeting the objectives. Surveying graduates is not new since the School has done this for years. The only change with ABET 2000 is the surveys are now done more systematically. Periodic assessments of student learning are done periodically to ensure that students are meeting the outcomes. ChE has developed a rotating schedule of assessments so that each of the nine outcomes is assessed every three years in at least two classes. Perusal of the outcomes shows that Outcomes 1, 2, 3, and 5 are technical outcomes that are assessed in the appropriate technical courses. For example, Outcome 5 is assessed in ENGR 13200 (Matlab), ChE 30600 (AspenPlus) and ChE 32000 (statistical packages) since all three classes have computer laboratories. Outcomes 4, and 6 to 9 are professional outcomes. Outcome 7 (communication) is assessed in several courses such as ENGL 10800, COM 11400, ChE 43500 and ChE 45000. Outcomes 4, 6, 8, and 9 are taught and assessed in the professional seminar series. In addition, in 2010 AIChE announced that safety (included in outcome 3) must be explicitly taught and assessed in the future. Safety will be included in most courses and will be assessed in ChE 34800 (kinetics and reactor design) and 45000 (design). Before ABET 2000 the preparation for ABET was mainly done by one professor—the ABET coordinator in the School—with modest help from a few other professors. For the 1995 visit Nick Delgass successfully shouldered this necessary but unrewarding task. With ABET 2000 the ABET coordinator (Steve Beaudoin for the 2001 ABET visit and David Corti for the 2007 ABET visit) is busier than ever, but now all faculty teaching undergraduate core courses must become involved in assessment and in preparing for the ABET visit.

Left: The ACS/IBM control laboratory was established in 1983.
Right: Current computer laboratory.

ABET visits are an inspection. Similar to all inspections the group being inspected puts its best foot forward and in the process consumes a fair amount of time. However, there is no doubt that the specific attention on assessment of what the students know and can do has helped improve undergraduate engineering education.

Purdue University also is accredited by the North Central Association of Colleges and Schools Commission on Accreditation and School Improvement (NCA-CASI)[54]. This is a university-wide accreditation (known as a regional accreditation) that is not as detail oriented as the ABET accreditation of a single program. The most recent visit of Purdue was in 2009 and the university was accredited for the full ten years. Both undergraduate and graduate programs (NCA started reviewing graduate programs in 2005[55]) needed to do assessments of student outcomes. Since the ABET assessment of the undergraduate programs is more thorough than NCA requires, it was easy to adapt it for NCA. After a bit of kicking and screaming, the graduate committee buckled down and developed graduate student outcomes and did an assessment of the graduate students in 2008.

Steve Beaudoin (left) and David Corti (right) have taken on the necessary task of coordinating the ABET accreditation effort.

In 2002 the construction of the new Forney addition to CMET allowed the School to dream of curriculum improvements that were not feasible without these additional facilities. This was the real start of the development of Fundamentals Labs to help make the somewhat abstract topics covered in the transport courses, ChE 37700 and 37800, and the kinetics and reactor course, ChE 34800, more concrete. Professor Jim Caruthers, who spear-headed the effort to develop the Fundamentals Labs, calls current students "'the point-and-click generation—one in which the computer has replaced the workbench and the tools used by professional engineers educated in the 19th and 20th centuries.' Caruthers recalls his own youth when his dad took him out regularly to work on cars. 'My dad showed me how to change a spark plug, change the car brakes. We went out and did mechanical things together,' he says. 'Today's engineering student often has never touched anything mechanical with their hands prior to joining Purdue. They come here and get lecture courses and more than likely don't touch anything until their senior year.'" (The quote is from Lee Lamb[56]) Perusal of the plans of study in the appendices shows that in 1950 and earlier engineering education was hands-on. But rising costs, the need to cover more theory for the engineering science revolution, the changing role of engineers in industry, and the changing student population have drastically decreased hands-on learning in all fields of engineering

According to Caruthers the goal of the development of the Fundamentals Labs was to "deliver a hands-on education in a way that's cost-effective in terms of space and cost of instructors and technicians to run it"[56] The development group realized that an old technique—

common in chemistry and physics—demonstration labs of lecture concepts modified to be hands-on for the students could keep costs down while using hands-on learning to supplement the theory students learn in their lecture courses. "We're able to illustrate four basic principles in three courses using the same lab and technician, and we need no new faculty members because this is just added into the existing curriculum," says Caruthers.[56] The ultimate purpose of the fundamentals lab is to give students examples of what's happening in the lecture—and why it makes sense. For most students a hands-on educational component is critically important, and it does not hurt students who can understand engineering from the lecture alone. Without the hands-on component a student may be able to do calculations, but "ultimately the student will not understand why in the world it matters." And understanding why it matters is critical. In essence, the fundamentals labs bring the hard-to-grasp theoretical concepts of transport and chemical reactors to life. For example, Caruthers explains "In lecture, we might discuss the basics of heat conduction and how heat moves down a pipe or rod. Then we'll go into the lab and measure the phenomenon."[56] Since the lab is used four days a week, the technician has time to set up new experiments for the next week and to store the old ones.

Students in Fundamentals laboratory in Forney addition, fall 2009.

David Corti, currently the Director of the Undergraduate Program, beta-tested the fundamentals labs with 88 students with ChE 37800 in Spring 2007. Corti noted that the lecture-with-lab combination does more than bring the abstract to life. It teaches valuable lessons to the students, mainly that getting measurements in a lab is a difficult process and requires careful and sometimes slow experiments. "Students don't think about how time consuming it is to get important data," says Corti. "The students are now getting more experience working in teams, and in writing lab reports." Thus, the labs help the School ensure that students meet Outcomes 2, 4, and 7 listed above. He stated, "I hope it also demonstrates that we deal with equations not for the sake of doing math, but that equations actually describe what's going on."[56] This aspect is key to ensuring that Outcome 1 is satisfied by the students.

Despite large classes, the faculty maintains its dedication to the education of the students. An enormous amount of time is spent in upgrading the content of courses. Even if the course has the same number and title for almost 50 years (e.g., ChE 205/20500) the textbook, the syllabus, the content, the problems, and the teaching method will evolve significantly. A brief history of the present undergraduate, dual-level, and graduate courses of the curriculum is offered in the next several pages. The evolution of these courses is a good example of the major educational changes that have occurred in chemical engineering during the past century. During this time period many electives, which are not reviewed here, have been offered from one to three times but have then disappeared. Elective courses disappear because of a lack of student interest or because of a lack of interest among current faculty.

One of the trends that will be clear after reading the descriptions of the current electives is that the School has difficulty offering all of the interesting electives that the faculty is capable of teaching. This difficulty has been true most of this century and it was exacerbated in Fall 2010 as the School tried to meet the Dean's Curriculum Challenge. In December 201057 the faculty voted to raise the minimum number of students in an elective course from five to eight. This restriction does not apply for courses being taught for the first time, and it does not apply if a professor volunteers to teach the course as an overload. Note that minimum limits on course numbers are not new. In January 1998 students were informed that "500-level courses which have less than ten students may be cancelled."[58]

Evolution of ChE Undergraduate Courses of the School

Required Undergraduate Courses

ChE 20000 and ChE 30000: Chemical Engineering Seminar and ChE 40000: Professional Guidance.

The seminar series started as a one credit ChE 491, Professional Guidance and Inspection Trips (see Appendix H). Former seniors will attest that the inspection (plant) trips were great fun. In 1972 the zero credit ChE 200 and ChE 300 seminars were added as orientation courses. ChE 491 was still worth one credit. The inspection trips continued; however, they became logistically difficult to manage. After 1981, the seminar became the zero credit sequence of ChE 200, 300 and 400. The purpose of these required orientation courses is to inform students of the various areas in chemical engineering, to assist them in selection of electives suited to their particular abilities and interest, to instill a sense of professional ethics and responsibility, to discuss job opportunities and job search methods, to explore graduate study opportunities. The first two seminars are zero credit, but are required for graduation. The ChE 40000 course gained one credit in Fall 2011 after repeated requests from the students. The various courses in the sequence have been coordinated/taught by a number of professors. Currently Mrs. Linda Davis is in charge.

ChE 20500: Chemical Engineering Calculations.

ChE 20500, the first ChE course taken by sophomores, is one of the oldest courses of the School, having been organized and taught by Lovell for the first time in the fall of 1937 as ChE 140. Initially an elective, it became a required sophomore course in 1941 (ChE 40). Lovell continued teaching it until 1946, followed by Doody until 1953. In the fall of 1953 it was changed to ChE 201 (always, with the same title). In the 1950's it was taught by Doody, Hite, Myers, Tucker, Woods, Tierney, Morgen and Sesonske. In 1957, an attempt was made to combine ChE 201 and ChE 202 (*Elementary ChE Thermodynamics*) in one course, ChE 203. The experiment failed and a new course, ChE 205, with the same title as ChE 201 was created and first taught in the fall of 1962. Reklaitis developed an approach to the teaching of this introductory ChE course, publishing a book titled Introduction to *Material and Energy Balances* in 1983 that was used until the late 1990's. Many professors taught it from the 1960's to the current time; including Baertsch, Barile, Beaudoin, Delgass, Eckert, Emery, Koppel, Reklaitis, Schneider, Wang and Wankat. In January 2011 the credits were increased from three to four to add a two hour recitation every week to help students who struggled with the material.

ChE 21100: Introduction to Chemical Engineering Thermodynamics.

Undergraduate thermodynamics was introduced as a senior required course in the fall of 1945 by J.M. Smith (ChE 10). In earlier years, elective courses in Mechanical Engineering covered the educational needs of the students in this area. J.M. Smith, Holcomb, and Bennett taught this course until 1953. In other sections of this book we have discussed how Smith wrote his most successful book, Introduction to Chemical Engineering Thermodynamics, as a result of his involvement in this course. In the fall of 1953, this course became ChE 410 and it was again a senior required course. It was taught as such by J.M. Smith, Van Ness, Bennett, and Myers until 1957 when it was changed to a required junior course and renumbered as ChE 310. In its new format it was taught by Emery, Sesonske, Briggs, Case and Shannon until the fall of 1963 when it took the number ChE 311. After 1981 it has been offered during the second semester of the sophomore year, and was relabeled as ChE 211 in 1987. The instructor of ChE 311/211 for more than thirty years was R. Squires, with short interruptions by other professors, such as Franses, Albright, Peppas, and Talbot. Before he retired, Squires developed additional educational tools for this course in the form of TV-taped problems[28], etc. After the last time Squires taught the course in Spring 1998, professors teaching the course were Corti, Franses, Lauterbach, Gil Lee, Litster, Won, and Yuan. Because of the large amount of material that needs to be covered, ChE 211 was increased from three to four credits in Spring 2010 by adding a two hour recitation every week.

ChE 30600: Design of Staged Separation Processes.

ChE 206, Stagewise Operations, was developed and introduced around 1970 as a two credit course ChE 206 covering distillation, absorption and extraction processes, previously included in unit operations or transport courses. In the fall of 1981, this course was changed to the three credit ChE 306 to better reflect its content and educational level, and it became a required junior course. Faculty members who have taught this course include Andres, Beaudoin, Eckert, Gil Lee, Peppas, Wang, Wankat and currently Houze. Wankat wrote a book entitled *Equilibrium Staged Separations*, now in its 3rd edition as, *Separation Process Engineering* that has been used as the textbook since 1985. In 1999 after a survey of recent graduates showed that the graduates thought their computer training was not as good as that of graduates of other ChE programs, an Aspen Plus computer laboratory was added to the course. The course now has two lectures and one two-hour computer laboratory session each week. Recent graduates have reported that they are well prepared for industry in this area. Wankat wrote articles about teaching separations with commercial simulators[59] and the history of separations[60].

ChE 32000: Statistical Modeling and Quality Enhancement.

ChE 320 grew out of ChE 244, *Data Analysis and Statistical Modeling*, which in turn spun out of a successful earlier elective course, ChE 525, developed by Greenkorn, Kessler and Eckert in the early 1970's. The original data analysis course was discussed by Greenkorn and Kessler in a 1974 article[44]. Often given as a multipurpose video-taped course, ChE 525 (known as the Bob and Dave show) became an integral part of the curriculum. Greenkorn and Kessler prepared the book *Modeling and Data Analysis for Engineers and Scientists* as the textbook for this course. ChE 244 was first taught in the fall of 1981 as a required two credit sophomore course that was taught by Eckert or Kessler. It was converted to a three credit junior course in 1991 and included a computer laboratory. In 1999 this course was moved to the second semester of the sophomore year because the material was very useful for students doing internships and co-op. In addition to Eckert and Kessler, the course has been taught by Baertsch, Blau, Harris, and Pekny. ChE 32000 and earlier variations have been extensively praised by industrial employers.

ChE 34800: Chemical Reaction Engineering.

A kinetics and reaction engineering course for undergraduate students was not offered until 1953, probably because of the faculty's impression that the various existing unit processes courses offered the necessary information in this area. Unfortunately, the unit processes courses offered very specific information about the reactions involved in the process, but did not provide the in-depth analysis of kinetics that would allow graduates to analyze any reaction. In the fall of 1953 Woods introduced the course ChE 526 *Process Kinetics*, which was originally a dual-level elective. He taught it continuously until the fall of 1964 when it became a required senior (later junior) course as ChE 439, *Reaction Kinetics and Chemical Equilibrium*. In its new format the course was taught by Woods, Delgass, Tsao, Koppel, Peppas, Squires and others until 1981 when it became ChE 348 under its present title. Since 1981 it has been taught by Andres, Baertsch, Delgass, Doyle, Franses, Martínez-Sáenz, Modak, Peppas, Ribeiro, Takoudis, Thomson, and Tsao. One of the major development efforts for ChE 34800 in the first decade of the 21st century was the development of a "Fundamentals" laboratory as part of the course. To accommodate the extra time required by the students to do laboratory experiments, ChE 34800 was increased from three to four credits in Fall 2010.

ChE 37700: Momentum Transfer and ChE 37800: Heat and Mass Transfer.

Two courses on Unit Operations (ChE 135 and 136) were introduced by Clifton Lovell in the fall of 1934 to replace the courses ChE 101 and 102 on *Elements of Chemical Engineering* that had been introduced by Peffer as ChE 1 and 2 in 1911. It would not be correct to assume that Peffer was teaching unit operations in these two courses. Indeed, the 1930-31 *Bulletin of Purdue University* offers the following description of ChE 101 and 102.

> Plant apparatus, machinery and fundamental processes of large-scale production. Current practice in the design and construction of various types of apparatus, through the study of trade catalogues.

In 1935, Lovell changed the goals of ChE 135 and 136, by introducing ChE 134 Elementary Unit Operations as a required junior course, and offering ChE 137 and 138, Unit Operations as required courses for seniors. It is these two courses, ChE 137 and 138 that can be considered the forerunners of today's ChE 37700, 37800 and 30600. Indicative of the modern educational spirit of Lovell was the description of these two courses in the 1936-37 *Bulletin*. "A more advanced study of unit operations with special consideration of the quantitative aspects as applied to design and operation."

ChE 137 and 138 were required senior courses taught by Lovell and his assistant R. B. Moore. After Lovell's resignation due to his health problems, they were taught by Holcomb (1946-48) and then by Doody and Bennett (1948-59); they became required junior courses in 1945. Starting in September 1950, and for the next nine years, Bennett and Myers—often assisted by Doody—developed these courses into the "heart" of the undergraduate ChE program. The title of the courses remained the same (the numbers changed to ChE 537 and 538 in 1953) until 1957, although the 1953-54 *Bulletin* clearly shows that the content of both courses was transport processes plus unit operations.

> Quantitative problems in the operation of chemical process equipment, including fluid flow, heat transfer, evaporation, drying, distillation, etc. Special emphasis on design calculations.

In the fall of 1957 ChE 537 became a four credit course on *Fluid Flow and Heat Transfer* (ChE 337) and ChE 538 a four credit course on *Mass Transfer* (ChE 338). ChE 338 included mass transfer and unit operations such as distillation, absorption and extraction. The harmonious collaboration of Bennett and Myers led to the undergraduate textbook Momentum, *Heat and Mass Transfer*, which included these unit operations. Faculty members who taught these courses from 1957 until 1968 were Bennett, B.D. Smith, Coughanowr, Emery, Doody, Koppel, Myers, Shannon, Briggs, Case, Sesonske and Kessler. After 1968 Greenkorn and Kessler formed a successful team that taught transport phenomena in these courses either as a seven credit sequence ChE 337/338 or in a short lived experiment with a five credit ChE 337 followed by an optional two credit ChE 339 *Transport Phenomena II* (the other option was ChE 525 *Data Analysis*). This experiment clearly did not serve our graduates and in 1981 the sequence became two required transport courses ChE 377 and 378. [As mentioned earlier, the ChE separation processes were moved to ChE 206 and then to ChE 306.] During that period Greenkorn and Kessler wrote the textbook *Transfer Operations*. From the late 1970's until 1986 Ramkrishna, Caruthers, Wang and Houze taught 337 (since 1981, ChE 377) and Wang, Ramkrishna, Caruthers and Peppas taught ChE 338 (since 1981, ChE 378). Since then, these two courses have evolved under the guidance of Basaran, Beaudoin, Harris, Houze, Kessler, Kim, Sevick-Muraca, and Thomson in ChE 377 and Basaran, Caruthers, Corti, Greenkorn, Houze, Kessler, Gil Lee, Liu, Peppas, and Wang in ChE 378. Developments in the 2000's focused on adding "Fundamentals" laboratories to both courses. To allow for the extra time required of students in the laboratory ChE 37700 was increased from three to four credits in Fall 2010 and ChE 37800 was increased to four credits in Spring 2011.

ChE 43500: Chemical Engineering Laboratory.

The currently required senior laboratory course includes experiments which are directed towards reaction kinetics, reaction engineering, separations, control and design. Laboratory courses at Purdue have had a long history. In the summer of 1935 Clifton Lovell started teaching ChE 139, Chemical Engineering Laboratory, as a required course for students between their junior and senior years. For 20 years, this "summer session" was a requirement for all ChE's. After 1941, ChE 140, *Unit Operations Laboratory* (which had been initiated also in 1935), was also transferred to the summer session. After Lovell's death, Holcomb and then Doody were in charge of these courses. In 1953 both courses were renamed *Unit Operations Laboratory* with new numbers, ChE 539 and ChE 540, with Tucker in charge. In the summer of 1957 the unpopular summer session was abolished and ChE 539/540 were split into ChE 339 offered during the junior year and ChE 440 offered in the senior year. After Tucker left, Emery was placed in charge of the laboratory equipment. He was ably assisted by technicians Hoyt Herron and then Jim Snell followed by Ken McGlothlin. In the spring of 1964 the junior course was renumbered as ChE 344 and ChE 440 became ChE 445. The laboratory portion of ChE 456 (ChE 456L) was absorbed into ChE 445 in the fall of 1981, ending a long tradition that started with Sherman's old pyrometry laboratory course (see discussion of ChE 45600). Various innovations in student project presentation and evaluation of the required reports of ChE 344 were described in an article29. In 1982 an alternative combined course for the honors program students (ChE 345 then ChE 496) was prepared from some of the experiments of ChE 344 and ChE 445. The honors course was discontinued in 2004. Caruthers, Delgass, and Houze taught the Honors Laboratory.

Left: The other side of chemical engineering: Henry C. Lim and James M. Caruthers playing table tennis at a Catalyst Club meeting in September 1977.
Right: The other side of chemical engineering. Faculty performing a skit at the 1981 *Razz-Banquet*. From left to right: Emmanuel G.Koukios - who was a Visiting Assistant Professor from 1980 to 1982 -, Alden H. Emery, Frank S. Oreovicz, P.C. Wankat and R.G. Squires.

In 1985 ChE 344 was moved to the first semester of the senior year and ChE 445 was moved to the second semester. These courses were renumbered as ChE 434 and 435 in 1987. Frank Oreovicz was in charge of evaluation and improvement of the students' writing styles in 344, 345, 445, 434 and 435 from 1979 until 2007. After Emery retired, Wayne Muench, a Ph.D. chemist with considerable industrial experience, was hired in January 1995 to be in charge of the equipment and to help teach the laboratory courses. Wayne retired in 2008. The unit operations laboratory technician during this time were first Jim Snell, then Ken McGlothlin followed by Ken's son Rick McGlothlin who is the current technician. After the development of the Fundamentals Laboratories in ChE 34800, 37700, and 37800; it became clear that parts of many of the ChE 43400 experiments were also included in the Fundamentals Laboratories and that the ChE curriculum was very heavy in laboratory experiences. ChE 43500 was increased to four credits by adding some material from ChE 43400 to the three credit ChE 43500 in Fall 2011. ChE 43400 was taught for the last time in Fall 2010 and ChE 43500 as a three credit course for the last time in Spring 2011. Faculty members who taught ChE 344, 434 and 43400 from 1964 until Fall 2010 include Albright, Chakraborty, Eckert, Emery, Franses, Houze, Kessler, Lauterbach, Martínez-Sáenz, Muench, Okos, Ribeiro, Tsao, Wang and Wankat. Faculty involved in teaching ChE 445, 435 and 43500 from 1964 to 2011 include Eckert, Emery, Franses, Houze, Martínez-Sáenz, Morgan, Muench, Okos, Ribeiro, Squires, Wang, and Wankat.

ChE 45000: Design and Analysis of Processing Systems.

The senior design course crowns or is the capstone of the educational program of undergraduate students. It is the course where all the knowledge acquired in four years merges in one common goal, that of the design of an industrial plant. The philosophy of instruction in this course mirrors the changing industrial conditions and needs. For example, whereas in the 1960's design of a petrochemical plant was a sine qua non of a design course, today a biochemical or polymerization process may be used as the main case-study of the course.

A course in *Plant Design and Lay-out* (ChE 116) was introduced in the ChE curriculum in the fall of 1926; it was taught by Bray, Peffer and Sanders and was a required senior course. It was dropped from the curriculum in 1945. ChE 529 became the design course in 1955 until ChE 450 was established in the spring of 1965. Since that time the faculty has vacillated on the amount of design required. In the early 1970's a second required design course, ChE 449 (*Fundamentals of Process Design*) was added to the first semester of the senior year. This two semester sequence survived until 1982 when the curriculum reverted to a single capstone design course. Because it proved to be quite difficult to cover the necessary engineering economics and design in a single three credit capstone design course, IE 343 (*Engineering Cost Analysis*) was added as a sophomore course in 1990. In 2009 the faculty decided to drop IE 343 and go back to a two semester design sequence with a three credit ChE 449 and two credit ChE 450. Before the design sequence could be taught, economic limitations and the Curriculum Challenge from Dean Leah Jamieson (see box) led to abandonment of this plan and development of a four credit ChE 45000 that will include engineering economics. This new course will be taught for the first time in Spring 2012. Various faculty numbers have taught the design courses including Agrawal, Albright, Andres, Houze, Kessler, Koppel, Malone, Martínez-Sáenz, Pekny, Rekliaitis, Thomson, Tsao, Venkatasubramanian, Wang, Wankat, and Woods plus industrial assistance from Joseph Alford and Tom Malizewski.

ChE 45600: Process Dynamics and Control.

The predecessor of ChE 456 is probably the oldest required course in the School, although its contents have totally changed since its inception. In 1915 George Sherman, then in the Physics Department, started teaching PHYS 12 *Radiation and High Temperature Measurement*, a course on "the measurement of high temperature by resistance thermoelectric radiation and optical methods." In 1923 the course was changed to PHYS 112, *Pyrometry and Radiation*, and became a required course in the senior year of Chemical Engineering. When Sherman moved to Chemical and a course on *Engineering Instrumentation*, ChE 155. The last sentence in the description of ChE 155 in the 1941-42 *Bulletin of Purdue University* shows that this was the beginning of control in the School.

> The measurement, recording, and controlling of various quantities, including pressure, temperature, flow, viscosity; applications of telemetering, electronics.

Sherman taught his course from 1937 until 1960. The course number was changed to ChE 555 in the fall of 1953, and its number and title to ChE 455, *Process Control* and Instrumentation, in 1957 when Coughanowr started teaching it as well. A laboratory was a required corequisite since its inception. After Sherman's retirement in 1960, Coughanowr and Koppel developed it into the premier undergraduate control course in the country (ChE 456 since the fall of 1964). The textbook Process Systems Analysis and Control was an offspring of the course and their collaboration. After Coughanowr's departure in 1966, Koppel shared the teaching responsibilities with Williams, Weigand, and Lim, plus Dr. Kayihan while Weigand was on leave of absence as an NSF Program Director. The laboratory course became an independent course ChE 456L in 1965 and was incorporated in ChE 445 in 1981. In the 1980's Prof. Andres also taught the course. The use of computer control simulations and IBM's ACS process control software became a component of the course in 1983. From 1993 to 1996 Doyle taught 456. In the last 12 years ChE 456/45600 has been taught by Chakrabarti, Jay Lee, Pekny and Venkatasubramanian.

ChE 54000: Transport Phenomena.

ChE 540 was developed in the early 1970's as a more advanced elective course in transport phenomena (supplementary to ChE 337 and 338) as a two credit course with an additional credit of 541. It was taught by Greenkorn and Kessler. In 1982 ChE 540 and 541 were consolidated into a single three credit ChE 540 elective. Currently ChE 540 remains as three credits, but it is partly required and partly elective since it is required for students in the ChE Honors program and an elective for other students. In addition to honors students, it is highly recommended for seniors intending to go to graduate school. It is also required of non-ChE, first-year graduate students before they take ChE 62000. In this preparation role ChE 54000 has saved many students from being caught later in the transport meat-grinder in highly ranked graduate schools. It has been taught yearly since 1994 by Basaran, Caruthers, Curtis, Greenkorn, Hillhouse, Houze, Kim, Ramkrishna, Sevick-Muraca, Wang and Wiest.

Undergraduate ChE Electives

With the designation by ChE that all the ChE electives would be dual level courses in 1964, until the mid-1990's the only truly undergraduate ChE electives were ChE 411 and 412. ChE 442 and ChE 461 were renumbered from 542 and 561 in the mid-1990's, and Neal Houze developed a new 400 level course, ChE 46300 in Spring 2008. ChE 33000, which was a required course, was made an elective for the class graduating in May 2012.

ChE 33000: Principles of Molecular Engineering.

This course was first offered as ChE 597A, *Engineering Properties of Molecular Materials* and as *Principles of Molecular Engineering* in the early 1990s by Andres, and was offered in Fall 1993 as a required course by Lackritz as *Properties of Molecular Materials*. In spring 1995 it became ChE 430 with the current title. Lackritz taught the course in 1995 and 1996, and after that Andres taught it until 2002. The course was renumbered as ChE 330 before the 2001 offering. In 2002 Lauterbach taught it followed by Hillhouse until 2009 when Won took over and then Wu in 2011. The course description is, "Application of concepts of atomic and molecular bonding, solid microstructure, phase equilibria, and rate processes to the design of solid materials for specific engineering objectives." This course is a great example of the visionary leadership of the Purdue ChE School as it was introduced ahead of its time, when nanotechnology was at its infancy. Unfortunately, the undergraduate students never understood the importance of the course, and ChE 33000 is now an elective.

ChE 41100: Chemical Engineering Science Research Problems and ChE 41200: Chemical Engineering Design Research Problems.

Although not a course in the true sense of the word, ChE 411 has the distinction of being the oldest subject in continuous existence in the course catalogue. A course, ChE 111, was established in the fall of 1925 under the title Chemical Engineering Problems and under the direction of Peffer, Bray, and Anderegg of the Chemistry Department. It was intended for "undergraduate honor students (and) provides an opportunity for *original investigation* (author's italics) on special problems in chemical engineering." It became ChE 411 in the fall of 1953 but its title remained the same for 56 years (1925-81); it was changed in 1981 to reflect the nature of the research done and a design research course (ChE 412) was added. ChE 411 has been for more than 85 years the vehicle by which undergraduate students can obtain credit for independent research projects under faculty supervision. Over the years it has nurtured many future researchers and it continues to be an important contributor to the diversification of our students' education. Research in science education clearly shows the advantages of involving undergraduate students in research— in addition to improving grades, students who do research are more likely to go on to graduate school61. The organization of ChE 411 projects and the use of undergraduate students in research is discussed in an article[30]. Over the years many professors have supervised students working on ChE 411 projects, and it is not uncommon to have undergraduate students as co-authors of papers. To give some flavor of the projects available, the **ChE 41100 – ChE 41200 or HONORS Research Projects** for the 2010-2011 academic year are shown below:

Ronald P. Andres and **W. Nicholas Delgass:**

1. Nanoparticle Fabrication of Electric Storage Capacitor
2. Superparamagnetic Nanoparticles as MRI Contrast Agents
3. Synthesis and Characterization of Novel Bimetal Clusters applications

Osman A. Basaran:

1. Drop dynamics: experimental analysis & ultra-fast digital imaging of singularities during drop formation & coalescence
2. MEMS and ink jet printing: innovation through fundamental studies
3. Drop-based methods for making particles and capsules for controlled release and ceramics applications
4. Nonlinear Dynamics and Chaos in Chemical Engineering

Gary E. Blau:

1. Evaluation of Novel Math Model Building Tools
2. Technical Analysis of Time Series Data for Stock Selection

James M. Caruthers:

1. Engineering Properties of Polymers
2. Molecular Design of Polymers and Polymer Composites
3. Kinetics of Polymerization

Raj Chakrabarti:

1. Computational Methods for Optimization and Control Spectroscopy

David S. Corti:

1. Entropic Forces in Colloidal Dispersions
2. Molecular Theory of Bubble and Droplet Formation in Metastable Fluids
3. Development of Lecture Demonstrations for Thermodynamics
4. Colloidal Stability of Inks and Pigment Dispersions (Co-Advised with Prof. Franses)

Elias I. Franses:
1. Separations of Chiral Molecules with Applications to Pharmaceuticals (Co-Advised Prof. Linda Wang)

Michael T. Harris:
1. Surface Properties of Biotemplates
2. Pharmaceutical Powder Characterization using Microwave
3. Interfacial Dynamics of Aqueous Drops Suspended in Vegetable Oils
4. Electrodispersion Precipitation and Alginate Microspheres

R. Neal Houze: CHE 412 ONLY (junior or senior standing in CHE)
1. Laboratory Project Development

Michael R. Ladisch:
1. Liquid Chromatography Modeling
2. Enzyme Mimetics
3. Protein Chromatography

James Litster:
1. Fundamentals of Roll Compaction of Powders
2. Experimental and modeling Studies of Wet Granulation
3. Microfluidic Crystallization

Julie C. Liu: (Honors or 2 semester CHE 411 commitment):
1. Patterned Biomaterials to Direct Cell Fate
2. Injectable Scaffolds for Cartilage Regeneration

John A. Morgan: (Honors or 2 semester CHE 411 commitment):
1. Biodiesel Production from Algae

Martin Okos:
1. Measurement of Viscoelastic Properties of Food Biopolymers
2. Analysis of the Effect of Processing on Food and Biological Product Quality
3. Minimization of Waste Production and Energy Consumption in Food Processing

R. Byron Pipes:
1. Nanocomposites and Celluar Polyimides
2. Cellular Polyimides
3. Combustion/gasification kinetics of single coal/biomass particles

Doraiswami (Ramki) Ramkrishna:
1. Crystallization and Precipitation Processes
2. Bioreactor Modeling and Control
3. Fischer-Tropsch Reactor Modeling
4. Simulation of Bubble Column Reactors
5. Kinetic Effects of Chemotherapeutic Drugs

Fabio Ribeiro:
1. Improving the Performance of Automotive Engines: NOx Traps
2. Generation of hydrogen using the water gas shift reaction

Kendall Thomson:
1. Multi-scale molecular modeling of protein-dynamics and function

Arvind Varma:
1. Hydrogen Generation for Fuel Cell Applications
2. Catalytic Conversion of Biodiesel Waste Product Glycerol to High-Value Chemicals

Nien-Hwa Linda Wang: (Two semester commitment of 411 or 412, or Honors BS Thesis)
1. Protein Separations
2. Recovery and Purification of Pharmaceuticals
3. Chromatography for Chemical or Biochemical Separations

You-Yeon Won:
1. Polymer -Based Gene Delivery
2. Self- Assembly of Colloids and Polymers at Air-Water Interfaces

Yue Wu:
1. Synthesis and Characterization Nanostructured Thermoelectric Materials

Chongli Yuan: (Honors or 2 semester CHE411 commitment)
1. DNA-guided self assembly of metal nanoparticles.
2. Structural characterization of protein-DNA supramolecular complex using fluorescence spectroscopy.
3. Recombinant protein synthesis and purification.

ChE 44200: Chemistry and Engineering of High Polymers.

Polymer processes were covered in ChE 629 by Shreve, Lottes, and Brink until Golding introduced ChE 542 to the curriculum in the fall of 1955. Albright, L.C. Case, Golding and Eckert taught the course in the late 1950's and 1960's, and Albright and Eckert taught it in the 1970's. The original textbook was Golding's notes then his book *Polymers and Resins*, published in 1959. After Golding left Purdue, Albright prepared a privately published manuscript entitled *Chemistry and Engineering of High Polymers* that was used as the textbook. Albright's lecture notes also served as the nucleus that led to his book *Processes for Major Addition-type Plastics and their Monomers*. Because ChE 542 was very popular with juniors and seniors, it was renumbered ChE 442 in the mid-1990's. Lackritz and Dr.Balaji Narasimhan (Ph.D. '96, now professor of ChE and Associate Dean of Engineering at Iowa State University) taught the course in the mid-1990's. Caruthers taught ChE 442/44200 most of the years that it was offered after that although Yuan taught the course in Fall 2010.

ChE 46100: Biomedical Engineering.

Bob Hannemann developed this popular one credit introduction to biomedical engineering in 1969 (originally as ChE 561) and has taught it every fall since that time. In addition to introducing students to the vocabulary of medicine and the major systems in the body, the course illustrates where chemical engineers can have an impact in medicine. Guest lecturers have participated in the teaching of this course, including Ash, Barile, Theofanous, Weigand, Wang, Franses, and Peppas. Efforts to offer ChE 561as a three-credit course both in 1972 (ChE 597E) and 1979 (ChE 597H) were not successful. This course attracts a number of students from outside ChE.

ChE 46300: Applications of Chemical Engineering Principles.

After listening to the chemical engineering students lament the paucity of very practical courses that would prepare them to be immediately useful in their first industrial jobs, Neal Houze developed ChE 46300 in Spring 2008. The official course description "Team-based design projects in materials transport, heat transfer, mass transfer, separations, chemical reactors. Emphasis on team operation and decision-making. Consideration of current technical challenges, societal and economic issues," only hints at the very practical nature of this course. In a few years this course has become one of the most popular undergraduate elective courses in the School. Current plans are to teach it every fall.

ChE 49700: Process Safety Management.

Based on the strong suggestions of the Industrial Advisory Council to teach more safety; the AIChE decision to explicitly require safety training be assessed in future ABET accreditation visits; the volunteering of assistance from experienced alumni Deborah Grubbe, Steve Swanson and Ron Cutshall; and the experience of staff member Linda Davis in industrial safety; Mike Harris volunteered to help develop this safety course with assistance from Deb, Steve, Ron and Linda. It was first taught in Spring 2011 to 27 enthusiastic students. The objective of the course is to "develop knowledge of process safety management in the process industries—including hazard identification, hazard analysis and risk management." In the absence of an acceptable textbook, the reference *Guidelines for Risk Based Process Safety*, Center for Chemical Process Safety (CPPS), AIChE, 2007, was used. This course is expected to be offered on a regular basis. Deb, Steve and Ron are writing a textbook on process safety.

Dual Level (Undergraduate/Graduate) Courses, 50000 Level

Dual level courses are designed to serve the educational needs of seniors and first year graduate students. Over the years, some of these courses became almost exclusively undergraduate elective courses, which is currently frowned upon by the Purdue Graduate School. These courses had to be renumbered as 40000 level courses. Others are populated predominantly by graduate students with a sprinkling of undergraduates. Courses that are still listed in the catalog but have not been offered for a number of years (e.g., ChE 51000, *Intermediate Thermodynamics*) and courses that are unlikely to be taught because the professor interested in teaching the course has retired or left Purdue (e.g., ChE 57700, *Flow Through Porous Media*) will not be discussed.

ChE 52500: Biochemical Engineering.

Biochemical engineering is very popular with both undergraduate and graduate students, and ChE 52500 (initially ChE 597T) is a most successful elective course. It was developed and introduced to the curriculum by George Tsao in the spring of 1976. In the mid-1980's it was team-taught by Tsao and Michael R. Ladisch of the School of Agricultural and Biological Engineering. After this period,the course was taught yearly by Tsao until 2001 when John Morgan took over the course. The course currently covers enzyme kinetics, mathematical models of microbial growth, bioreactor design and operation, genetic and metabolic engineering, plant and animal cell culture, and purification of biological products.

ChE 53600: Particulate Systems.

Particulate systems are critically important but under studied in standard ChE undergraduate curricula in the United States. To partially correct for this a course in particulate systems is regularly offered as an elective. This course was developed by Jennifer Sinclair in 1998 as ChE 597S. She taught the course every year until she left Purdue in 2004. In 2004 the course was assigned its permanent number. After 2004 the course was not taught until 2007 when it was picked up again by Litster and Harris, and was then taught again in 2010. The current catalog description is an "overview of the fundamental concepts in particulate systems including particle characterization, particle size measurement, sedimentation, fluidization, gas and liquid conveying, particle storage, fluid-particle separation, particle size enlargement and reduction, particle mixing and hazards associated with the handling of particulate solids."

ChE 54300: Polymerization Reaction Engineering and Reactor Analysis.

Shortly after his arrival at Purdue, Peppas developed five new courses in addition to the existing 542 (now 44200) in the area of polymer science and engineering. The educational philosophy in polymer science and engineering at Purdue that led to five courses is described in an article by Peppas[32]. After Nicholas left for Austin, Texas, no one had the energy to keep a total of six different polymer courses operating. ChE 44200, 54300, and 54400 are the surviving courses. ChE 54300 was introduced in the fall of 1979 as ChE 597M and took its permanent number in 1983. A description of this course appeared in a 1980 article[33]. The current catalog description is, "Polymerization kinetics, polycondensation, gelation, radical polymerization, ionic polymerization, copolymerizations, Ziegler-Natta polymerizations, polymerization in bulk, solution, suspension and emulsion, modeling, stochastic processes, Z-transforms, batch, CSTR and tubular reactors, stability analysis, computer control, separation, and drying." Of course, in elective courses professors do not feel strictly bound by the content listed in the catalog and the actual content delivered depends upon the professor teaching the course. ChE 54300 has been offered on a somewhat irregular basis by Won.

ChE 54400: Structure and Physical Behavior of Polymers.

ChE 54400 was introduced to the curriculum by Peppas as ChE 597G in the spring of 1978 and became a regular course in the fall of 1981. Throughout the 1980's Peppas and Caruthers taught this course, which was populated by seniors and graduate students. An offspring of this course was a very successful intensive summer course on *Structure and Properties of Polymeric Materials* which was offered as a one-week continuing education course by Caruthers and Peppas in the mid-1980's. Lackritz started teaching the course in 1992 and continued until 1996 with the exception of 1995 when Peppas taught 544. After fall 1996, offerings have been sporadic. Recently, Won has offered this course as it alternated with ChE 44200 and 54300.

ChE 55500: Computer Integrated Process Operations.

In fall 1993 Profs. Doyle, Pekny, Reklaitis, and Venkatasubramanian jointly developed this course as 597O Integrated Process Operations. The precursor was an advanced course in computer aided design, ChE 697G that was developed by Reklaitis in fall of 1981. ChE 597O was also taught jointly in 1995 and 1996. Because the professors interested in this course are also interested in and have developed a number of other courses, ChE 597O was not taught again until fall 2005 and 2006. After another four year break, the course was taught again (as ChE 55500) in fall 2010 by Venkatasubramanian. Since the subject matter, computer-aided process design and operation, has long been one of the major research areas in the School, there are always graduate students interested in taking the course.

ChE 55600: Fundamentals of Microelectronics Processing (VLSI).

This course covering various aspects of processing of materials for the microelectronics industry was developed as ChE 597D by Takoudis in the fall of 1985. The course was quite popular until Takoudis left in 1996. It was picked up again in fall 2004 and 2006 by Steve Beaudoin, who had taught a similar course at Arizona State University. The course emphasizes basic principles and practical aspects of advanced electronics processing. Emphasis is on crystal growth, epitaxy, lithography, and dry etching. There is every indication that this course would be popular if course schedules allowed it to be taught on a regular basis.

ChE 55700: Intelligent Systems in Process Engineering.

This elective, mainly taken by graduate students, was initially developed by Prof. Venkatasubramanian in 1989 as ChE 597V. The course is an introduction to Artificial Intelligence (AI) systems and their application in process engineering. He taught the course every year from 1989 to spring 1994, then again on a yearly basis from fall 1998 to fall 2001 and after that in spring 2007, 2008 and 2010. Unfortunately, enrollment has been low recently.

ChE 55800: Rate-Controlled Separation Processes.

The predecessor of ChE 558 was the course ChE 158, *Petroleum Technology*, introduced to the curriculum by Myers in the fall of 1951. It became ChE 558, *Petroleum Refinery Engineering*, in the fall of 1953 and it was taught by Myers, Tierney, Hite and Comings in the 1950's and by B.D. Smith and Briggs in the 1960's. In the late 1960's, Williams used it as a vehicle for discussion of intermediate level distillation. The course was reorganized by Wankat and offered in 1972 as *Equilibrium-Staged Separation Processes*, a mastery-learning course34 taken mainly by undergraduates. At that time it was infamous for its Tuesday-Thursday-Saturday class schedule—a cruel and unusual punishment no longer inflicted on students. After ChE 306 was developed in 1981, there was no need for an intermediate level equilibrium-staged separations course and ChE 558 was reorganized with its present title. Articles on its content were written by Wankat[35]. After 1987 Wang and Wankat alternated teaching the course although because of other duties and staffing difficulties requiring them to teach other courses they have been able to offer it only sporadically. Wang offered it most recently in 2007. Coverage varies depending on who is teaching the course and their current research interests. The current version of ChE 55800 is taken mainly by graduate students. Plans are to offer this course on a two year rotation.

ChE 597A/59700: Risk Management in the Development of New Products & Processes.

Although the 597 course number is supposed to be a temporary number, ChE 597A was first offered by Joe Pekny and Gary Blau in fall 1998 and has been taught by Pekny and/or Blau yearly until fall 2005 and then again from spring 2008 to 2010. The latest offering in spring 2011 was taught by Venkatasubramanian. The course is currently dually listed as IE 59000. The goal of the risk management class was to teach students how to use their quantitative chemical engineering skills to make decisions in all areas of their lives; from interpersonal relationships, to investing, to selecting a job, to working in a company, to managing a corporation. Early each semester , the uncertainty inherent in these decisions seemed to frighten the students. Class size has grown from a small cadre of about 10 students to over 50 students from both the Schools of Chemical Engineering and Industrial Engineering.

ChE 597E/59700 and ChE 597D/59700: Principles of Pharmaceutical Engineering, and Pharmaceutical Process Development and Design.

These two courses are offered as part of the NSF grant that formed the Pharmaceutical Engineering Research Center. Reklaitis and Venkatasubramanian were involved in the course development, and Reklaitis has been the usual professor. The "Principles" course was first offered in Spring 2005 while the Design/development course was first offered in Fall 2005. The former is intended to give an overview of the pharma industry, regulations and associated issues such as IP. The Design course is focused on process and unit operations used to make small molecule pharmaceuticals. Thus, it covers batch processing and all the usual batch unit operations (reaction, crystallization, solid-liquid separation, etc).

ChE 59700 Courses:

Every year a number of elective courses are offered under the temporary number 59700. Some of these courses will eventually gain permanent numbers as electives or required courses although most eventually stop being offered. In addition to the relatively long-lasting examples of 597A, 597D and 597E listed above, the recent offerings are listed to give a flavor of electives available to students over the last five years:

Battery Systems Engineering	Caruthers	Spring 2011
Particle Design and Processing	Litster	Spring 2011
Principles of Tissue Engineering	Liu	Spring 2011
Engineering Applications of Biological Molecules	Yuan	Spring 2011
Career, Teaming, & Entrepreneurial Methods Engr.	Pekny	Fall 2010
Introduction to Energy Storage Systems	Wu	Fall 2010
Electrochemical Engineering	Hillhouse	Spring 2010
Introduction to Quantum Control Engineering	Chakrabarti	Spring 2010
Advanced Solar Energy Conversion	Agrawal	Fall 2009
Particle Design and Processing	Litster	Fall 2009
Introduction to Nanoscale Science	Wu	Fall 2009
Principles of Tissue Engineering	Liu	Spring 2009
Advanced Solar Energy Conversion	Agrawal	Fall 2008
Advanced Solar Energy Conversion	Agrawal/Hillhouse	Fall 2007
Synthesis Separation Processes	Agrawal	Fall 2006

Undergraduates do education also: ChE Student Advisory Council kid's day activity with 5th to 8th grade students in Forney B124 in 2011.

The Graduate Curriculum

The development of the graduate educational program at Purdue was somewhat slower than the development of the undergraduate program. The early period (1911-1934) is one of a substandard graduate program with courses only in metallurgy, and after 1930 also in unit processes. During the period from 1934 to 1947 unit operations achieved some recognition in the graduate curriculum, although unit processes and organic chemical technology were the main research and educational areas for graduate students. Only after the introduction of thermodynamics by Smith in 1946, the various courses in transport processes by Bennett, Myers and Comings in the early 1950's and kinetics by Woods in 1955, did Purdue catch up with other major universities in graduate education. Courses in reaction engineering, applied mathematics and other areas of chemical engineering were introduced in the graduate curriculum mostly in the 1960's and 1970's. Although there have been disagreements about the amount of transport in the graduate core (it went from one to two and back to one course), the current four course core (ChE 610, Thermodynamics; ChE 620, Transport; ChE 630, Advanced Mathematics for ChE; and ChE 660, Kinetics and Reactor Design) was essentially set by the 1970's. Naturally, each course has evolved significantly since that time. Developments since then have involved the continual development of new electives, reduction in the number of courses required for graduation—from 13 to 10 to increase time for research—and training of teaching assistants.

In the fall of 1924 Bray introduced the School's first graduate course, ChE 108, Advanced Metallurgy, which by 1926 had become a senior course. In 1926 Maxwell started teaching the first truly graduate ChE course, ChE 210, Advanced Chemical Engineering. Here is a description of this pioneering course from the 1926-27 *Bulletin of Purdue University*.

> A mathematical study of physicochemical phenomena underlying fundamental operations of chemical engineering, as liquid and vapor phase reactions, fractionation and distillation, equilibria, electrochemistry, heat transfer, applications of colloid theory and selected topics.

Many of these topics are now covered in required courses in the undergraduate curriculum. Movement from introduction of new material at the graduate level to a senior elective to a required course in the curriculum is a common pattern.

Left: Eileen Van Wonterghem (BS 2011) doing research in Professor's Wang's Laboratory
Right: Rohit Khanna (BS '79) doing research with Professor Peppas in 1978.

Harold L. Maxwell was the first ChE professor who was noticeably concerned about the progress of the graduate program. His ChE 210 was based on the standards of the best courses at M.I.T. He used the book of W.H. Walker, W.K. Lewis and W.H. McAdams, *Principles of Chemical Engineering*, as a required textbook, and was the first to teach rudiments of kinetics, distillation and heat transfer. How unfortunate that this course was cancelled in 1930, when Maxwell resigned to go to DuPont.

By the late 1930's the graduate program had taken shape. For the M.S. degree there were two areas of specialization: general chemical engineering and organic technology. In addition to an original thesis, four core courses were required and the other four courses were electives acceptable to the thesis committee. In the general ChE option the core courses were ChE 226a (heat transfer), ChE 226b (distillation), ChE 226c (mass transfer), and ChE 227 (mathematical calculations)—all taught by Lovell. The recommended elective courses were Chem 285 and 286 (advanced physical chemistry), MGMT 107 (industrial personnel administration), and MGMT 104 (elements of accounting). In the organic technology option the core courses were ChE 228 and 229 (advanced unit processes) and Chem 263 and 264 (advanced organic chemistry). Recommended electives included heat transfer, distillation, and courses in speech and English.

For the Ph.D. degree another eight elective courses beyond the M.S. degree were required. For both degrees knowledge of a foreign language (preferably German) was required. The professional Ch.E. degree was the third advanced degree given by Purdue. Recipients were Purdue B.S. graduates who had completed four years of engineering practice and had written an appropriate thesis (see also Appendix Q). Students who had received an M.S. degree required only two years of industrial experience to obtain the professional Ch.E. degree. Nevertheless, this degree was not popular and it was dropped in 1952.

Left: A trying period in some student's stay in the School is the time he or she takes the dreaded sequence of the two junior transport courses. Here James M. Caruthers tutors his ChE 377 students.
Right: Roger Eckert teaching outdoors in 1978.

J.M. Smith, who arrived at Purdue in the fall of 1945, immediately introduced graduate (ChE 234) courses in ChE thermodynamics. Until then, thermodynamics was covered in mechanical engineering courses taken as electives by chemical engineering students. Finally, Comings introduced graduate courses in modern fluid mechanics and high pressure technology.

Probably the most important contributors to the graduate program during the 1950s and 1960s were Carroll O. Bennett and John E. Myers. They introduced or completely redesigned several courses that are still in existence today (see Table 7-7).

Table 7-7. Graduate Courses Introduced (i) or Redesigned (ii) by Bennett and Myers

Original #	Area	Current #
ChE 510	Fall 1953 (i)	ChE 510
ChE 527	Fall 1953 (i)	
ChE 158	Fall 1951 (i)	ChE 558
ChE 627	Fall 1953 (ii)	
ChE 620	Fall 1963 (i)	ChE 620
ChE 623	Fall 1954 (ii)	ChE 623
ChE 625	Fall 1953 (ii)	

The changes that Myers and Bennett made in the graduate curriculum were not universally acclaimed by the faculty. The result between 1955 and 1960 was turbulence, but not the type studied in fluids. One consequence of those turbulent years was it made active educators and researchers receptive to opportunities at other schools and led to Van Ness (1956), J.M. Smith (1957), Bennett (1959) and Myers (1966) leaving. During those times many of the graduate students of the School recognized the feuds among professors and the consequences for their education. For example, in 1985 professors Irving F. Miller (M.S. '56) at the University of Illinois and Herbert Weinstein (M.S. '57) at CUNY noted in discussions with Prof. Peppas that these feuds led to their departure from Purdue with M.S. degrees instead of continuing for the Ph.D.

Jack Woods introduced a graduate course in kinetics and reactor design (ChE 662) in Fall 1953 that was renumbered as ChE 660 in 1963, but it did not become a core course until 1966. Woods also redesigned the chemical processes course ChE 529 and made it a required process design course, which was moved into the undergraduate curriculum as ChE 450 in 1965.

The arrival of new faculty members after 1974 led to major changes in the entire graduate curriculum. This led to a change of the educational philosophy of the curriculum towards more fundamentals and less applications in these courses. Prominent among these changes was the reorganization of the 500 and 600 level courses, undertaken by Caruthers, Lim, Peppas, and Ramkrishna. These changes are shown in Table 7-8.

Table 7-8 Graduate Course Redesign in late 70's and early 80's

Course	Introduced (i) or Redesigned(ii)	Area	Faculty Responsible for Reorganization
ChE 620	Spring 78 (ii)	transport	Caruthers & Ramkrishna
ChE 624	Fall 77 (ii)	mass transfer	Peppas
ChE 630	Fall 77 (i)	mathematics	Lim & Ramkrishna
ChE 632	Fall 79 (i)	mathematics	Ramkrishna
ChE 635	Fall 81 (ii)	transport	Caruthers & Ramkrishna
ChE 645	Spring 78 (i)	polymer transport	Peppas
ChE 697M	Spring 82 (i)	transport	Peppas
ChE 697R	Spring 82 (i)	mathematics	Ramkrishna
ChE 697Y	Spring 84 (i)	polymers scaling laws	Peppas

With these changes, the current core courses in the graduate curriculum (ChE 610, 620, 630, and 660) were set. [ChE 610 grew out of J. M. Smith's graduate course ChE 234 and ChE 660 grew out of Woods earlier efforts.] For a period of years a second transport course, ChE 661, was required, but is now an elective. In late 1976 the faculty set the minimum course hours for PhD at 39, but with permission 36 might be acceptable[62]. Language courses did not count. In 1978 the graduate committee removed the 36 credit possibility[63]. In 1982, CHEM 605, Safety, became a required course for all new graduate students[64]. After considerable discussion over a number of years, the number of course credits required for graduation was reduced to 30 credits in 2005[65].

In 1975 the faculty agreed that two languages (English plus another language) were required for the Ph.D., and international students did not have to learn a third language[66]. A motion to eliminate the requirement of foreign languages was defeated at a 1984 faculty meeting[67] and finally eliminated in 1996[68] after interminable arguments.

Even though the University does not require a qualifying examination, at the insistence of Bennett, J.M. Smith and Van Ness, qualifying examinations were instituted in 1953 to screen students who wished to perform a Ph.D. thesis. In 1969 after the Graduate School removed the rule that there had to be a professor outside of ChE on Ph.D. committees, the School added this as a ChE requirement[69]. A procedure to "bypass" writing the master's thesis for students who unconditionally passed the qualifying procedure on the first try was introduced in 1974[70]. In 1980 an oral bypass report presented before the student's Advisory committee was required before the end of the third semester (summer does not count)[71]. Currently, very few Ph.D. students write master's theses. In 2009 after enormous discussions the former written qualifying examination was abolished and replaced by a combination of grades in the core courses, and a written and oral research presentation[72].

The University requires a Ph.D. preliminary examination at least two semesters before graduation. In one of recurring efforts to encourage students to graduate within a reasonable time frame, in 1984 ChE passed the rule that graduate students with a BS degree in chemical engineering had to take their preliminary examination before the end of their fifth semester[73]. Recently, this rule has been enforced except when there are extenuating circumstances. In 2005 a retake in the sixth semester was allowed and any students who had not passed the preliminary examination by the end of their sixth semester would have their support terminated[74].

In an attempt to increase the research output of the School, students are required to do some writing early, which will help when they write their thesis, and reduce the time to graduation; in 1997 the graduate committee noted that Ph.D. graduates are expected to have at least one published paper at the time they graduate[75]. Since granting agencies also want publications, most professors are happy to follow this rule.

In late 2007 it became clear that international graduate students had concerns about approvals of H1-B visas to be able to work after graduation. Since visas are only applied for in October, students who graduate between February-September have to wait until the next October date for companies to apply for a visa. This can be avoided if the students have a master's degree. The faculty agreed that students who have passed the PhD preliminary exam and have published at least one journal research publication will be eligible to receive a non-thesis MS degree[76]. This change is available to all students, but was particularly gratifying to the international students.

The time to complete the Ph.D. degree has long been of concern to both students and faculty. One difficulty with keeping the degree from taking too long is that there are times when the professor and/or the student can believe it is in their best interest to prolong the time to degree. From the professor's point of view, just when the student becomes really good and efficient at research, the student is ready to graduate. Another year (or two) will provide a significant increase in research results and papers. From the viewpoint of the student, if there is no job at the end of the tunnel, staying in the safe womb of paid graduate student research seems preferable to graduation. This is particularly true of international students who will have to leave the US if they do not find a position. Unfortunately, in the long term, it is not good for either professors (keeping students too long is seen quite negatively by students looking for an advisor), or students (the extra time for the Ph.D. stays on their resumes forever). To control this problem the School has set time limits on supporting students, set strict limits on dates to pass the qualifying and the preliminary examinations, spread out the load for TAs and limited the average number of hours per week a student is supposed to work as a TA, reduced the number of courses required for the Ph.D. from 13 to 10, reduced and then removed the foreign language requirement, eliminated the requirement that all students must write a master's thesis, and tried to provide assistance in obtaining full-time positions. Although all of these items help, because of the conflict of interest inherent in the advisor's position (a desire to accomplish as much research as possible versus concern for the student's best interests), keeping the Ph.D. at a reasonable number of years will remain a continuing battle. For students entering the graduate program with a BSChE degree, the average time to complete the PhD degree is currently 4.75 years, which compares well with national statistics.

Core Graduate Courses

Currently, all graduate students in ChE must take the four core courses ChE 61000, 62000, 63000, and 66000. A fifth course, ChE 62100 was a core course for several years, but is now an elective.

ChE 61000: Advanced Chemical Engineering Thermodynamics

Graduate thermodynamics appeared first as a course in the fall of 1946, introduced by J.M. Smith as ChE 234. It was changed to ChE 610 in the fall of 1953. The course includes advanced topics in classical thermodynamics and elements of statistical thermodynamics. Initially taught by J.M. Smith from 1946 until 1953, from 1954 to 1986 it was given by Bennett, Van Ness, B.D. Smith, Shannon, Emery, Squires, Chao and Greenkorn. The book *Thermodynamics of Fluids* by Chao and Greenkorn has been an offspring of this course. These authors described the philosophy of their approach to thermodynamics in a 1972 article[36]. Since 1986 this course has been taught by Chao, Corti, Franses, Talbot and Peppas. Recently, David Corti has taught this course most years.

ChE 62000: Transport Processes

In many ways the cornerstone course of our graduate program, ChE 620, was developed by Myers in the fall of1963. Before this course several other courses such as ChE 622, 624, 625 and 635 treated various aspects of transport phenomena. In the early days, Bird, Stewart and Lightfoot was the textbook used in ChE 620. More recently, this book was used off-and-on in the undergraduate courses ChE 377, 378 and 540, and is used only as a reference in 620; other more advanced textbooks and the unpublished notes of Ramkrishna have taken its place. From 1966 to 1986 this course was taught by Myers, Theofanous, Kessler, Houze, Greenkorn, Ramkrishna and Caruthers. More recent professors include Basaran, Caruthers, Ramkrishna and Sevick-Muraca.

ChE 63000: Applied Mathematics for Chemical Engineers

The first serious educational effort in the area of applied mathematics for ChE's was made by Myers, who introduced the course ChE 627 in the fall of 1953. In the 1960's this course became a course on statistical analysis of experiments; in 1984 it became a dual level course, ChE 597E. The present graduate course in applied mathematics was introduced by Ramkrishna in the fall of 1977 as ChE 697A and took its permanent number in the fall of 1981. The course has a heavy workload and covers the theory and ChE applications of most of the following mathematical topics: determinants, matrices and solution of systems of algebraic equations; differential equations including series solutions, Sturm-Liouville systems, and boundary value problems; complex variables including LaPlace and infinite Fourier transforms; and first order partial differential equations. Beaudoin, Caruthers, Franses, Lim, Pekny, Ramkrishna, Reklaitis and Thomson have taught this course since 1977.

ChE 66000: Chemical Reaction Engineering

ChE 226, the first graduate course introduced to the curriculum by Lovell in 1935, included elements of reactor design. In the 1940's it was divided into five courses and ChE 226e became the course on Chemical Engineering Kinetics. It was changed to ChE 662 in the fall of 1953. Doody and J.M. Smith taught it for some time after Lovell, followed by Van Ness and Woods in the 1950's. Throughout the 1960's Woods taught ChE 662 and its successor course ChE 660 which was started in the fall of 1963. The present ChE 66000 is a course addressing important aspects of chemical kinetics and reaction engineering. From 1963 to 1986 it was taught by Delgass, Ramkrishna, Takoudis and Woods. A 1983 article[37] by Takoudis analyzed the philosophy of this course. Takoudis offered the course until he left Purdue in 1996. The current course description is "Heat, mass, and momentum transfer in the design and analysis of chemical reactor systems. Optimization techniques applied to reactor design." In the last dozen years Profs. Delgass, Martínez-Sáenz, Peppas, Ramkrishna, and Thomson have taught ChE 66000.

ChE 62100: Advanced Transport Phenomena II

This course was first developed by Ramkrishna in 1989 as a required core course in the Ph.D. program as ChE 697F. After 2005, students had to select four of the five core courses. ChE 62100 was made an elective in 2009. The course description is, "momentum transfer with interfacial effects, transport in porous and multiphase media, transport in dispersed phase systems, heat transfer, and multicomponent mass transfer," although the actual coverage varies a bit based

based on the professor. ChE 62000 is a prerequisite. For the last dozen years the professors have been Basaran, Kim and Ramkrishna.

ChE 69700: Chemical Engineering Teaching Experience

This three credit course is required of all graduate students who are serving as teaching assistants (TA). The course was first developed in spring 2009 as ChE 59700 by Litster and Wankat and has been offered every semester since then. The course meets for one lecture a week. The other two credits are based on practical experience in the students' teaching assignments. The course introduces ideas of educational pedagogy; offers practical advice on running recitations, dealing with difficult students and grading; discusses methods to encourage active learning; explores academic careers, and requires the TAs to reflect on their experiences as a TA. Litster has been in charge of the course after spring 2009 with occasional guest lectures by Wankat.

Elective Graduate Courses

The courses described below are elective graduate courses that ideally are given once every two years, although some of the more specialized ones may be offered once every three years.

ChE 59700: Graduate Internship

Although this course has a 50000 number, it is only available to graduate students. In 1997 the faculty approved a graduate internship course ChE 696, which is now CHE 59700. Students usually sign up for one credit while they are doing summer and/or semester internships with companies, nonprofits or government. The faculty recommends students not pursue internships for the first summer, after that the decision is between the student and advisor. The advantage of having an internship course is that students remain students while on the internship. For U.S. students this means loans do not come due and in some cases they can still be covered on their parents' medical insurance. For international students they can do the internship with their student visa, which reduces the hassle for the students and the company enormously. Although internships are helpful for any student who has not had industrial experience, they are particularly beneficial to international students who want to find a job with a U.S. company after graduation.

ChE 61100: Advanced Topics in Chemical Engineering Thermodynamics

Developed in 1965 by Greenkorn, ChE 61100 covers advanced topics in thermodynamics such as partition and distribution function descriptions of fluids, molecular interactions by dispersion and electrostatic forces, Monte Carlo and molecular dynamics simulation of statistical ensembles, fluid surfaces and macromolecules. From 1969 until he retired, K. C. Chao taught this course. It then lay dormant until spring 1999. Since then it has been taught by Basaran and most often by Corti. The course has been on approximately a three year rotation since 2001

ChE 62300: Separation Processes

The advanced graduate course on separation processes is one of the four oldest graduate courses in the curriculum. Originally introduced by Lovell in the fall of 1935 as ChE 226, Advanced Unit Operations, this course was divided into five courses in 1941. ChE 226b was renamed Distillation and changed to ChE 223 in 1947. It was taught by Holcomb and then Bennett. Bennett and Myers continued teaching it after it became ChE 623 in the fall of 1954. In 1960 it was renamed Equilibrium Stage Separations and in the late 1960's and early 1970's was taught by Williams. In the mid-1970's Wankat added other emerging fields of separation science such as industrial chromatography and membrane separations, and changed its title to the present one. An outline of the contents of this course and a description of the similarities and differences of ChE 623 with respect to ChE 624 and 558 were published[38] in 1981 and a textbook was published in 1990[77]. In the late 1980's Wang started teaching 623 and has been the only teacher of the course (in 1990, 1992, 1994, 1996, 1998, 2007, and 2011) since then. Because the Curriculum Challenge requires restricting offerings of electives, the current plan is to merge ChE 623 and 558 into a new ChE 558 which will be offered every other year.

ChE 63200: Linear Operator Methods in Chemical Engineering

One of two advanced graduate courses on applied mathematics that can be taken after ChE 630, ChE 632 was introduced and taught by Ramkrishna as ChE 697A in the fall of 1979, changed to its permanent number in 1981, and is taught approximately once every three and a half to four years by Ramkrishna. It is based predominantly on functional analysis and its applications. The book I by Ramkrishna and Amundson is an accurate representation of the course's contents. A detailed analysis of the philosophy of education in this area appears in a 1979 article by Ramkrishna[39].

ChE 63300: Probabilistic Methods in Chemical Engineering

This is the second advanced mathematics course that students can take after ChE 63000. ChE 63300 covers probability, random variables, stochastic processes, population balances, stochastic differential equations, Brownian dynamics, Bridge processes, theory of fluctuations, and, most importantly, applications of this material to chemical engineering systems. A similar course was first taught at IIT-Kanpur in 1969 by Ramkrishna. At Purdue Ramki first presented a seminar version in the fall of 1976 based on his notes and a number of books and papers. In the spring of 1982 the first formal course (ChE 697R) was presented. A 1978 article by Ramkrishna[41] discusses some aspects of this course. During the last twenty years this course has been taught somewhat irregularly (1993, 1997, 1998, 2005, and 2008). However, it has been a cornerstone of advanced mathematical courses and much appreciated by students and alumni. For example, 25 years after he took it, Tony Mikos (MS'85, PhD 88), now a distinguished professor at Rice University, still identifies it as the course that changed his way of thinking in research. Considering that Tony works in tissue engineering, this is a great tribute to the course and Ramki Ramkrishna's far reaching educational contributions to the school.

ChE 65600: Advanced Process Control

An advanced process control course was developed by Koppel and first taught in the fall of 1963. An offspring of the early years of teaching this course was Koppel's book on Introduction to *Automatic Control Theory*. Others who taught the course in the 1970's and 1980's include Williams, Weigand and Lim. The course was taught in 1993 and 1997 by Doyle, and in 1999 and 2000 by Jay Lee and then lay dormant for ten years. It was revived by Chakrabarti in spring 2011.

ChE 66200: Catalysis

The present ChE 66200 is not to be confused with the pre-1960 ChE 662 course, which was the predecessor of the present ChE 66000 (see description). This advanced course in catalysis was given for the first time by Squires in the spring of 1966. Throughout the 1960's and 70's Squires and Delgass continued offering it with great success every second year. The course and its goals during that period were described by Delgass in a 1975 paper[40]. The Catalysis course has remained popular and is normally taught approximately every other year. For the last dozen years Riberio or Delgass have taught this course.

ChE 66600: Methods In Catalysis

Major changes in ChE research in the 1970's led to the introduction of a second, more specialized course in catalysis, which includes an in-depth analysis of the various spectroscopic and other techniques used in this research field. The course was organized and initially taught by Delgass, first as ChE 697D in the spring of 1978, and as ChE 666 since the spring of 1982. Delgass coauthored the monograph *Spectroscopy in Heterogeneous Catalysis Research* (1979) which incorporates many of the subjects of this course. Since 2005 Riberio has shared the teaching duties for 66600 with Delgass. Offerings have been erratic since fall 1998.

ChE 66800: Colloidal and Interfacial Phenomena

With the arrival of Franses at Purdue, a graduate course on colloids was recommended to the faculty in August 1980, first presented in the fall of 1981 (as ChE 697F), and since the fall of 1983 under its present number, ChE 668/66800. Because of the importance of applications of the material covered in the course [“Preparation, characterization, and stability of emulsions, aerosols, and other multiphase dispersions. Interparticle forces, electrokinetics, thermodynamics and kinetics of coagulation. Techniques for determining size, shape, orientation, and charge of particles. Capillary and wetting phenomena. Thermodynamics of interfacial tension and adsorption.”] in a wide variety of fields, ChE 66800 has remained popular and has been taught almost every other year since fall 1994.

ChE 68500: Educational Methods in Engineering

ChE 68500 was approved as a two credit experimental course in 1982 and first taught as ChE 697W, Educational Methods in Chemical Engineering in spring 1983. In 1991 the course was allowed to be included in Ph.D. plans of study, but not M.S. plans of study (the rationale is in the US one needs a Ph.D. to teach engineering). When Wankat proposed teaching this course as an overload to Andres, the School Head, Andres suggested working with Frank Oreovicz. This team continued to teach the course on a regular basis until 2006. After Oreovicz retired in 2007, the course was not offered until fall 2011 when Wankat will teach 68500 for the last time. After the first offering, the course was expanded from chemical engineering to all areas of engineering. At the time it was first offered, 68500 was the only course in the entire country that taught prospective engineering professors how-to-teach. Currently there are a number of such courses. The instructors published a textbook, *Teaching Engineering*[42], and seven papers on the course[43]. The School of Engineering Education may adopt this course as a service to the College of Engineering.

ChE 69700: Elective Courses

Every year a number of elective courses are offered under the temporary number 69700. Some of these courses will eventually gain permanent numbers as electives or required courses although most eventually stop being offered. The courses offered for the last five years give a flavor of the variety available:

Metabolic Engineering	Morgan	Fall 2010
Protein Engineering	Liu	Spring 2010
Electronic Structure, Theory & Modeling Chem Proc.	Thomson	Spring 2010
Finite Element Analysis in ChE	Basaran	Spring 2009
Finite Element Analysis in ChE	Basaran	Spring 2008
Electronic Structure, Theory & Modeling Chem Proc.	Thomson	Fall 2007
Finite Element Analysis in ChE	Basaran	Spring 2007
Electronic Structure, Theory & Modeling Chem Proc.	Thomson	Spring 2007
Finite Element Analysis in ChE	Basaran	Spring 2006

Left: David P. Kessler (left) and Lowell B. Koppel, the authors of important undergraduate textbooks, at a senior picnic in October 1964.
Right: W. Nicholas Delgass taught ChE 660 for many years (1976 picture).

Educational Publishing: Textbooks and Articles

"The very boundaries of what we mean by chemical engineering are determined to a significant extent by the textbooks. The publication of "Principles of Chemical Engineering" by Walker, Lewis, and McAdams ...shaped the field of chemical engineering for many decades afterwards."[78] For many years, Purdue's School of Chemical Engineering has been considered a leader in undergraduate education. It is therefore natural that some major successful textbooks have been written here.

Highlights of Textbook Writing at Purdue

At the AIChE Centennial Celebration AIChE recognized that three of the 30 Groundbreaking ChE Books were written by Purdue faculty during their tenure with ChE:

1. *Process Systems Analysis and Control* by D.R. Coughanowr and L.B. Koppel,
2. *Chemical Engineering Thermodynamics* by J.M. Smith and H.C. Van Ness, and
3. *Chemical Process Industries* by R. Norris Shreve.

R.N. Shreve's *Chemical Process Industries* was published in 1945 when Shreve was 60 years old. In its five editions, two of them with the collaboration of J. Brink and G. Austin, it had sold more than 180,000 copies in 1986. By 1947 it had already been accepted as a textbook[79,80] by 70 ChE Departments including those of Princeton University, University of Wisconsin, University of Minnesota and University of Illinois. Although not used as a textbook since about 1960, it remains a handy, although aging, handbook-type reference of industrial processes.

J.M. Smith's and H.C. Van Ness' *Introduction to Chemical Engineering Thermodynamics* was originally published by the senior author in 1949, when he was a young Associate Professor at Purdue. This text has taught three generations of chemical engineers and continues to be the most popular undergraduate thermodynamics text. Presently in its seventh edition published in 2005 (with M.M. Abbott as an additional co-author), the combined seven editions have sold more than 666,000 copies which makes it the best selling ChE text of all time. J.M. Smith, a gifted author of undergraduate textbooks, wrote his other best-seller, *Chemical Engineering Kinetics*, while at Purdue. Published originally in 1956, his book had a third edition (1982).

One of the most successful and influential undergraduate textbooks in the 1960's, *Process Systems Analysis and Control* (1965) by D. R. Coughanowr and L.B. Koppel nurtured two generations of ChE's throughout the world. It sold more than 120,000 copies by 1986 and at one time (1975) was used by 72% of the ChE Departments in the USA as a required text. Both authors used this text as undergraduates at Purdue with Koppel as the teacher (PCW) and in Greece (NAP). Peppas claims this book changed his thinking about chemical engineering and maybe it was also the reason why he accepted Lowell Koppel's offer to join Purdue over a number of other offers. The second edition was published by Coughanowr in 1991, and the third edition by Coughanowr and Steven LeBlanc was published in 2008.

In the early 1960's C.O. Bennett and J.E. Myers put together their thoughts on transport phenomena in a book entitled *Momentum, Heat and Mass Transfer* (1962). The third edition (1982) is currently out of print. The three editions sold more than 70,000 copies by 1986.

Other textbooks with significant impact on their times were written by J.L. Bray, B. Golding, and P. C. Wankat. Although not a textbook, we would be remiss if we did not mention Lyle Albright's enormous effort as editor to produce *Albright's Chemical Engineering Handbook*, CRC Press and Taylor and Frances Group, Boca Raton, FL, 2009. Only by a labor of love could this task be completed.

Table 7-9. Textbooks Published by Purdue Chemical Engineering Faculty

The following textbooks were published by ChE faculty members during the period they served at Purdue University. Monographs, professional books and edited collections are discussed in Chapter 8.

1925

J.L. Bray, R. Richards and C. Locke, *A Textbook of Ore Dressing*, McGrawHill, N.Y., 1925.

1929

J.L. Bray, *Principles of Metallurgy*, Ginn and Company, 1929.

1938

J.T. Fotos and J.L. Bray, *German Grammar for Chemists and Other Science Students*, Wiley, N.Y., 1938.

J.T. Fotos and R.N. Shreve, *Intermediate Readings in Chemical German*, Wiley, N.Y., 1938.

1940

J.T. Fotos and R.N. Shreve, *Advanced Reading in Chemical German*, Wiley, N.Y., 1940.

1941

J.L. Bray, *Non-Ferrous Production Metallurgy*, Wiley, N.Y., 1941 (2nd edition, 1948).

1942

J.L. Bray, *Ferrous Production Metallurgy*, Wiley, N.Y., 1942.

1944

R.N. Shreve and T.R. Olive, *Chemical and Metallurgical Flowsheet Book*, McGraw-Hill, N.Y., 1944.

1945

R.N. Shreve, *Chemical Process Industries*, McGraw-Hill, N.Y., 1945. (2nd edition 1956; 3rd edition 1967; 4th edition with J.A. Brink 1977; 5th edition with G.T. Austin 1984).

R. J. Raudebaugh, *Nonferrous Physical Metallurgy*, 1945. Reprinted by Pittman, 1952.

1946
J.L. Bray, *Patent Law and Procedure*, Purdue University, West Lafayette, 1946.
1948
J.T. McCormack, *Ore Minerals: Their Sources and Uses*, Edward Bros., Ann Arbor, MI, 1948.
1949
J.M. Smith, *Introduction to Chemical Engineering Thermodynamics*, McGraw Hill, N.Y., 1949 (2nd edition with H.C. Van Ness, 1959, 7th edition 2005 (with M.M. Abbott as an additional co-author).
1950
R.N. Shreve, *Selected Process Industries*, McGraw-Hill, N.Y., 1950.
1955
S. Glasstone and A. Sesonske, *Nuclear Reactor Engineering*, Van Nostrand, N.Y., 1955. In two volumes, 1963 (second edition, 1967; third edition, 1978).
1956
E.W. Comings, *High Pressure Technology*, McGraw-Hill, N.Y., 1956.
J.M. Smith, *Chemical Engineering Kinetics*, McGraw-Hill, N.Y., 1956. 3rd edition, 1982.
1959
B. Golding, *Polymers and Resins*, Van Nostrand, New York, N.Y., 1959.
C.O. Bennett and J.E. Myers, *Momentum, Heat and Mass Transfer*, McGraw-Hill, N.Y., 1962 (2nd edition, 1974; 3rd edition, 1982)
1963
B.D. Smith, *Design of Equilibrium Stage Processes*, McGraw-Hill, N.Y., 1963.
1965
D.R. Coughanowr and L.B. Koppel, *Process Systems Analysis and Control*, McGraw-Hill, NY, 1965. 3rd edition Coughanowr and S. LeBlanc, 2008.
1968
L.B. Koppel, *Introduction to Automatic Control Theory*, Prentice Hall, Englewood Cliffs, N.J., 1968.
1972
R.A. Greenkorn and D.P. Kessler, *Transfer Operations*, McGraw-Hill, N.Y., 1972.
1975
K.C. Chao and R.A. Greenkorn, *Thermodynamics of Fluids*, M. Dekker, N.Y., 1975.
1980
C.P.L. Grady and H.C. Lim, *Biological Wastewater Treatment: Theory and Applications*, M. Dekker, N.Y., 1980.
R.A. Greenkorn and D.P. Kessler, *Modeling and Data Analysis for Engineers and Scientists*, TIS Publications, Bloomington, IN, 1980.
1982
R.A. Greenkorn, *Flow Phenomena in Porous Media*, M. Dekker, N.Y., 1982.
1983
G.V. Reklaitis, *Introduction to Material and Energy Balances*, Wiley, N.Y., 1983.
1984
D. Ramkrishna and N.R. Amundson, *Linear Operator Methods in Chemical Engineering*, Prentice-Hall, Englewood Cliffs, N.J., 1984.
1988
Wankat, P.C., *Equilibrium-Staged Separations*, Elsevier, N.Y., 1988. After 1992, Prentice-Hall was publisher.
1989
Venkatasubramanian, V., *Knowledge-Based Systems in Process Engineering: Case Studies in Heuristic Classification*, CACHE Corporation, Austin, TX, 1989.
1990
Wankat, P.C., *Rate-Controlled Separations*, Elsevier, London, England, 1990. Currently published by Springer.

1993
Wankat, P.C. and Oreovicz, F.S., *Teaching Engineering*, McGraw-Hill, N.Y., 1993.
1999
D. P. Kessler and R. A. Greenkorn, *Momentum, Heat and Mass Transfer Fundamentals*, Marcel Dekker, N.Y., 1999.
2007
Wankat, P. C., *Separation Process Engineering, 2nd edition of Equilibrium-Staged Separations*, Prentice-Hall, Upper Saddle River, NJ, 2007.
2012
Wankat, P. C., *Separation Process Engineering. Including Mass Transfer Applications*, 3rd edition, Prentice-Hall, Upper Saddle River, NJ, 2012.

In addition to publishing textbooks, their interest in education has led many faculty members to publish papers on engineering education topics. The most common topics are new teaching methods, course development, curriculum development and new material that should be included in the curriculum. Engineering education articles published while the faculty member was at Purdue are shown in Appendix W.

Since research collaborations are discussed in detail in Chapter 8, it is useful to note that there have also been significant collaborations in engineering education. Greenkorn and Kessler developed several textbooks together, Squires and Reklaitis produced a number of videotapes and wrote articles on their efforts, and Wankat and Oreovicz were prolific authors with a total of 65 educational columns, articles and a textbook. It is our group of gifted educators who continue the outstanding educational tradition of the School, a tradition that started with Peffer, Bray, Shreve and Lovell.

Rankings and the Value of a Purdue BSChE Degree

In the end, education is all about the students and the graduates. So, how valuable is the BSChE degree? (Ratings and value of Ph.D. degrees are discussed at the end of Chapter 8.)

A number of stories of outstanding accomplishments by graduates of the School have been sprinkled throughout the first six chapters of this History. There have also been a number of rankings of undergraduate engineering colleges and chemical engineering programs which tell a story of excellence.

The 1976 report[81] of New Engineer was a thorough evaluation of engineering and chemical engineering programs around the country. The survey was conducted among more than 1000 department heads. In positive responses to the question "Which undergraduate school's degrees are most valuable in landing good jobs in teaching or university-based research?" Purdue ChE was ranked sixth; the University of Minnesota was first. Finally, Purdue ChE was tied for first place with the University of Minnesota in positive responses to the question: "Which undergraduate school, other than your own, has produced the most successful participants in your own graduate department in recent years?" The same Journal offered an evaluation of all engineering programs. Purdue University was ranked first ahead of M.I.T. and the University of California at Berkeley in positive responses to the question: "Which undergraduate school, in your opinion, offers academically the best engineering programs overall (taking into account all degree programs)?"

The methods to rank institutions are only limited by one's imagination. In 1978 Noble[82] used the replies of industrial managers to rank ChE departments according to "'users' preference". Purdue University was ranked first in the country for its undergraduate educational program, ahead of the University of Wisconsin (third) and M.I.T. (fifth). Glower83 analyzed the careers of all persons included in the 1977 *Who's Who in Engineering* to establish which School produced the most successful graduates. Purdue Engineering was ranked fourth in total number of alumni cited, behind M.I.T., University of Illinois and University of Michigan. In chemical engineering, Purdue was ranked eighth; University of Michigan was first and M.I.T. was second.

US News & World Report[84] released its most recent national rankings of undergraduate programs in August 2010. The *US News & World Report* rankings of undergraduate programs are very closely correlated with their rankings of graduate programs. Purdue ranked #8 among engineering programs at doctoral-granting universities, tied with Carnegie-Mellon and Cornell. Purdue ranked #9 in 2009, tied with Cornell and University of Texas-Austin. The School of Chemical Engineering ranked 12th as compared to 13th in 2009. The top 20 undergraduate chemical engineering programs in 2010 are listed in Table 7-10.

It appears that a college or program can be ranked about anywhere one wants by changing the criteria. For example, the Forbes 2010 ranking[85] placed Purdue University (the entire university – not engineering) as number 362 out of 610 programs ranked. On the other hand, Purdue University has long been a favorite of corporate recruiters.

Finally, one of the most important values for graduates is obtaining professional jobs. A 2010 poll of top corporate recruiters by the *Wall Street Journal*[86] released in September 2010 asked the recruiters which schools produced the best graduates overall. The poll rated Purdue overall as number 4 (Penn State was number 1), and in engineering Purdue was number 2 (Georgia Tech was number 1).

Table 7-10. *US News & World Report*
Top 20 Undergraduate ChE Programs in 2010[84].

1	Massachusetts Institute of Technology
2	University of California--Berkeley
3 (tie)	Stanford University
	University of Minnesota
5 (tie)	University of Texas--Austin
	University of Wisconsin--Madison
7	University of Illinois--Urbana-Champaign
8	California Institute of Technology
9	Georgia Institute of Technology
10	Princeton University
11	University of Delaware
12	Purdue University
13	University of Michigan
14	Carnegie Mellon University
15	Cornell University
16	Northwestern University
17	University of California--Santa Barbara
18	Texas A&M University
19	University of Florida
20 (tie)	North Carolina State University
	Pennsylvania State University

Improving Purdue ChE Education

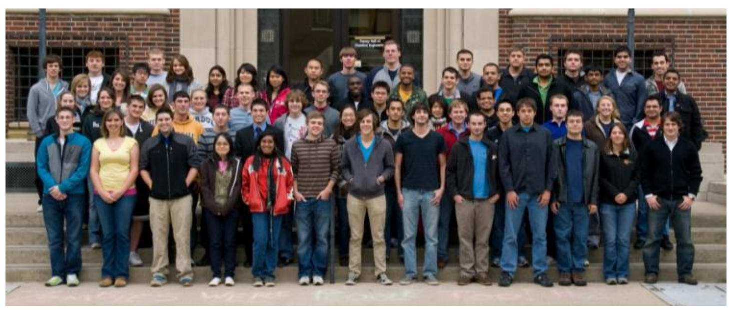
There is no doubt that Purdue provides a good education in chemical engineering and that the Purdue name or brand is valuable in an industrial career. However, we need to always be careful that the quality of the education does not slip, and to always be on the lookout for ways to improve the education.

First, what can the School do within its resources to improve ChE education at Purdue?

1. Insist new professors take a course or workshop on how to teach. Industry makes sure new hires are trained in the duties they will perform. The School should also.
2. Improve the mentoring of new faculty in teaching. A mentoring program is in place, but mentoring on teaching is not always covered well.
3. Continue to encourage and provide modest resources (e.g., secretarial assistance) for textbook writing (one of the goals mentioned by the Industrial Advisory Council). It would be a shame for Purdue to lose its role as a leader in the development of ChE textbooks.
4. Encourage transparency and sharing. The faculty should have some knowledge of what is covered in every core course in both the undergraduate and graduate programs. Continue to encourage professors to share notes and come to agreement on the level of difficulty of courses to make the program more consistent from year to year.

5. Encourage more professors to audit courses to increase their knowledge and ease the development of new areas of expertise.

Students come to Purdue to earn degrees in Chemical Engineering. Our latest graduates – the class of 2011 are shown in these two photos. Hopefully many of them will return as successful alumni for the School's sesquicentennial in 2061.



Second, what can alumni do to help improve Purdue's ChE education?

1. The top item for industry is to provide meaningful internship and co-op jobs for undergraduate and graduate students. Professors often hear complaints that graduates are not ready for industrial careers and that the students are unfamiliar with a particular industry. Internships/co-op can help with these problems, and the School cannot provide them. Note that the ChE 597 Internship course means graduate students can remain students while serving an internship, which means that the company does not have to worry about immigration rules.
2. Second, provide the School with well-thought out advice. Because we heard loud and clear from many sources that teamwork and statistics were needed in industry, teamwork is now required in most classes and ChE 320 (statistics) is a required course. The best forum for offering this advice is the Industrial Advisory Council because the advice is from many industries.
3. Provide support. Support includes money, an open door for site visits, and providing expertise. There are always worthy students who could use the psychological and economic boost from an award or scholarship. Continual replacement of equipment and computers is needed to maintain a quality education, and the normal budget

does not include these items. Plant trips can be extremely informative to students (and professors). Along with advice, expertise can be very helpful and sometimes essential. A good example is the 2011 development of ChE 497, Process Safety Management. Without the encouragement and assistance of Deborah Grubbe (BS '77), Stephen Swanson (BS '71, Ph.D. '75) and Ron Cutshall (BS '71), the course would not have moved forward.

References and Bibliography

1. O.A. Hougen, *Chem. Tech.*, 10 (Jan. 1979).

2. O.A. Hougen, *Fifty Years of Chemical Engineering Education in the United States*, Kyoto University, 1957.

3. R. Aris, *Ind. Eng. Chem. Fund.*, 16, 1 (1977).

4. R.L. Pigford, *Chem. Eng. News*, 190 (April 6, 1976).

5. Groppe, H. (Chair), A Report by The Septenary Committee on Chemical Engineering Education for the Future, "Chemical Engineering Education for the Future," Sponsored by Department of Chemical Engineering, University of Texas-Austin, Edited by J. R. Brock and H. F. Rase (1985).

6. Sciance, C. T., "Chemical Engineering in the Future," *Chem. Engr. Educ.*, 21, 12 (Winter 1987).

7. Westmoreland, P. R., "Chemistry and Life Sciences in a New Vision of Chemical Engineering," *Chem. Engr. Educ.*, 35, 248 (Fall 2001).

8. Mosto, P., M. Savelski, S. H. Farrell, and G. B. Hecht, "Future of Chemical Engineering: Integrating Biology into the Undergraduate ChE Curriculum," *Chem. Engr. Educ.*, 41, 43 (Winter 2007).

9. Cussler, E. L., D. W. Savage, A. P. J. Middelberg, and M. Kind, "Refocusing Chemical Engineering, *Chem. Engr. Prog.*, 98 (1), 26S (January 2002).

10. Cussler, E. L. and J. Wei, "Chemical Product Engineering," *AIChE J.*, 49, 1072 (2003).

11. Varma, A., "Future Directions in Chemical Engineering Education: A New Path to Glory," *Chem. Engr. Educ.*, 37 (4), 284 (2003).

12. Letter of J.J. Hinman, Jr. to J.T. Fotos, July 6, 1939.

13. E.H. Hartwig, description of education program, in ChE Archives, no date.

14. Letter of R.N. Shreve to H.C. Peer, November 30, 1932.

15. R.N. Shreve, *Unit Processes in Organic Technology*, unpublished leaflet, 1934.

16. R.N. Shreve, "Why Unit Processes," unpublished paper, 1938.

17. R.N. Shreve, Industrial Importance of Unit Processes, seminar at the University of Louisville, March 8, 1940.

18. R.N. Shreve, *Unit Processes March on*, leaflet, 1948.

19. R.N. Shreve, *Chemical Fundamentals of Unit Processes*, 1945.

20. R.N. Shreve, "Evolution of Unit Operations and Unit Processes," presentation at ASEE Meeting, Madison, WI, September 1, 1918.

21. R.N. Shreve, *Unit Processes*, unpublished leaflet, 1938.

22. Memorandum of J.L. Bray to R.N. Shreve and C. Lovell, October 8, 1936.

23. Memorandum of J.L. Bray to R.N. Shreve, January 5, 1938.

24. R.N. Shreve, *Graphic Instruments in Chemical Processes*, circa 1941.

25. R.N. Shreve, "Some Observations Regarding Chemical Engineering," December 5, 1938.

26. Lee Lamb, "A Great Place to Call Home," ChE Impact Winter 2006.

27. *Purdue School of Chemical Annual Report*, July 1, 1996-June 30, 1997, p. 7.
ChE Newsletter, Spring 1999.
ChE Impact, Winter 2006.
ChE Faculty Minutes, November 9, 2006.

28. R.G. Squires and D.V. Frank, *Chem. Eng. Educ*., 17, 117 (1983).

29. P.C. Wankat, R.N. Houze and R.G. Barile, *Proceed. Frontiers Educ. Conf*., 2, 37 (1977).

30. N. A. Peppas, *Chem. Eng. Educ*., 15, 135 (1981).

31. N.A. Peppas, AIChE Meeting, manuscript 9c, November 1978.

32. N.A. Peppas, *SPE Techn. Papers*, 26, 656 (1980).

33. N.A. Peppas, *Chem. Eng. Educ*., 14, 188 (1980).

34. Wankat, P.C., "A Modified Personalized Instruction-Lectuure Course," in J.M. Biedenbach and L.P. Grayson (eds.), *Proceedings of the Third Annual Frontiers in Education Conference*, Purdue U., Apr. 1973, ASEE-IEEE, N.Y., 144-148, (1973).

35. P. C. Wankat,, "An Elective Course in Separation Processes," *Chem. Eng. Educ*., 15, 208-213 (Fall 1981).

36. K.C. Chao and R.A. Greenkorn, *Chem. Eng. Educ*., 6, 158 (Fall 1972).

37. C.G. Takoudis, *Chem. Eng. Educ*., 17, 158 (1983).

38. P.C. Wankat, *Chem. Eng. Educ*., 15, 208 (1981).

39. D. Ramkrishna, *Chem. Eng. Educ*., 18, 172 (1979).

40. W.N. Delgass, *Chem. Eng. Educ*., 8, 158 (1975).

41. D. Ramkrishna, *Chem. Eng. Educ*., 12, 14 (1978).

42. Wankat, P. C., and F. S. Oreovicz, *Teaching Engineering*, McGraw-Hill, New York, 1993. Available free at https://engineering.purdue.edu/ChE/AboutUs/Publications/TeachingEng/index.html

43. Wankat, P. C., and F. S. Oreovicz, "Teaching Prospective Engineering Faculty How To Teach," *Intl. J. Engr. Educ*., 21, 925-930 (2005).

44. R.A. Greenkorn and D.P. Kessler, *Chem. Eng. Educ*., 7, 176 (1974).

45. ChE Faculty minutes, April 17, 1975.

46. ChE Faculty minutes, June 26, 1980.

47. ChE Faculty minutes, January 21, 2010.

48. ChE Faculty minutes, April 24, 2008.

49. R. R. Rhinehart, "An Analysis of Enrollment Cycling in ChE," *Chemical Engineering Education*, 35 (1), 50-57 (Winter 2001).

50. Undergraduate Committee Minutes of May 2, 1996 meeting, June 10, 1996.

51. Wankat, P. C., *The Effective, Efficient Professor. Teaching, Scholarship and Service.* Allyn & Bacon, Boston, 2002, pp. 139-147.

52. Memo from Dean Leah H. Jamieson, "Curriculum Challenge," August 6, 2010.

53. http://www.abet.org/ Accessed March 4, 2011.

54. North Central Association Commission on Accreditation and School Improvement http://www.ncacasi.org/ Accessed March 4, 2011.

55. Audeen Fentiman quoted in ChE Faculty minutes, January 10, 2008.

56. Lee Lamb, "Blackboard Concepts Come to Life," *Purdue Chemical Engineering Impact*, 4-5, Winter 2007-08.

57. ChE Faculty minutes, December 2, 2010.

58. School of Chemical Engineering, "Undergraduate Master List," January 14, 1998.

59. P. C. Wankat, "Using a Commercial Simulator to Teach Sorption Separations," *Chem. Engr Educ.*, 40, 165-172 (2006).

60. P. C. Wankat, "Separations: A Short History and a Cloudy Crystal Ball," *Chem. Engr Educ.*,43(4), 286-295 (2009).

61. Tobias, S., *Revitalizing Undergraduate Science: Why Some Things Work and Most Don't*, Tuscon, Arizona, Research Corporation, 1992.

62. Dec 16, 1976 Faculty meeting minutes.

63. Graduate committee minutes, Sept. 6, 1978

64. Dec 2, 1982, Graduate committee minutes.

65. Feb. 21, 2005 Faculty meeting minutes.

66. June 2, 1975 Graduate Committee minutes.

67. Feb 23, 1984 faculty meeting minutes: "The foreign language requirement was discussed. After much discussion a motion was made and seconded to drop the requirement. The motion was defeated."

68. Nov 16, 1996 Faculty meeting minutes: "The Graduate Committee brought before the faculty a motion to eliminate the foreign language requirement for PhD students. A discussion was held and the motion carried."

69. Sept 18, 1969, Faculty meeting minutes.

70. October 17, 1974 faculty meeting minutes.

71 Aug. 28. 1980 Faculty meeting minutes.

72. 10/1/09 Faculty meeting minutes.

73. June 21, 1984 Faculty meeting minutes.

74. Nov. 17, 2005 Faculty meeting minutes.

75. March 24, 1997, Graduate committee minutes.

76. 2/14/08. Faculty meeting minutes.

77. Wankat, P.C., *Rate-Controlled Separations*, Elsevier, London, 1990. (Currently published by Springer in print on demand format.)

78. Bird, R. B., "Book Writing and Chemical Engineering Education. Rites, Rewards, and Responsibilities," *Chem. Engr. Educ*., 17, 184 (Fall 1983).

79. News Bulletin, McGraw-Hill Book Co., December 1947.

80. Memorandum of R.N. Shreve to A.A. Potter, January 7, 1948.

81. Anonymous, *New Engineer*, 21 (December 1976).

82. R.D. Noble, paper No. 2208, ASEE Meeting, June 19-22, 1978.

83. D.D. Glower, *Engin. Educ*., 70, 788 (1980).

84. *US News & World Report, Best Colleges*, August 2010.

85. *Forbes*, Special Report, America's Best Colleges, August 11, 2010, <http://www.forbes.com/lists/2010/94/best-colleges-10_Americas-Best-Colleges_Rank_14.html> accessed March 30, 2011.

86. T. Evans, "State Schools Lure More Employers," *Wall Street Journal*, p. B1, Monday, September 13, 2010.

87. M. Longo Cohn, letter to N. A. Peppas, March 31, 2011.