The History of Chemical Engineering and Pedagogy: The Paradox of Tradition and Innovation

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Abstract

The Massachusetts Institute of Technology started the first US chemical engineering program six score years ago. Since that time, the chemical engineering curriculum has evolved. The latest versions of the curriculum are attempts to broaden chemical engineering to add product engineering, biology and nanotechnology to the traditional process engineering, chemistry and energy. Although there have been attempts to add flexibility, the chemical engineering curriculum remains monolithic (all students take almost identical sequences of courses) and hierarchical. Chemical engineering textbooks have tremendous staying power because authors have time to adapt to slow changes in the curriculum. Chemical engineering has been somewhat schizophrenic – chemical engineering research has covered all areas in which chemical engineers believe they can make a contribution, but departments have been notably unwilling (until recently) to expand the borders of the undergraduate curriculum.

Despite the conservatism of ChE departments, chemical engineering has been at the forefront of helping new professors learn how to teach and individual chemical engineering professors have been leaders in the push for engineering education reform. Yet, most ChE professors insist on lecturing. Examples of chemical engineering leadership in pedagogy include the Chemical Engineering Division of ASEE Summer School every five years, the Division's publication of the journal *Chemical Engineering Education,* and leadership in teaching professors how-to-teach*.* Individual efforts include the development of the guided design method, introducing Problem Based Learning into engineering, laboratory improvements and hands-on learning, the textbook *Teaching Engineering,* and the championing of cooperative group learning.

This paper will provide a brief history of chemical engineering programs, curricula and pedagogies.

Introduction and Early Programs

In 1888 MIT started Course X (Course refers to curriculum), which began as a mechanical engineering curriculum with time devoted to the study of chemistry, and eventually became chemical engineering [1, 2]. MIT did not claim invention of chemical engineering but noted that similar engineers were active in Europe [3]. Davies [4] starts his history of chemical engineering with the ancient Greeks and continues to the 1887 series of lectures presented by George E. Davis at the Manchester Technical School in England. These lectures, which were published over the next few years in the *Chemical Trade Journal,* are often considered the start of formal education in chemical engineering. Since this is the 100th anniversary of the American Institute of Chemical Engineers, we will generally limit our comments to the American experience and refer readers interested in the history of chemical engineering in other countries to the many fine chapters in Furter [5].

The historical role of MIT in starting chemical engineering education in the USA has been well documented [1-3, 6]. The initial Course X, founded by Lewis Mill Norton, was contained in the department of chemistry. Chemical engineering became a separate department in 1920 with Warren K. Lewis as the head. Perhaps the first American text in chemical engineering, *Elements of Fractional Distillation,* was published by MIT professor Clark Shove Robinson in 1922 as part of McGraw-Hill's International Chemical Series [7]. This was followed in 1923 by the seminal *Principles of Chemical Engineering* by William H. Walker, Warren K. Lewis and William H. McAdams [8], which laid the quantitative foundations of the discipline and utilized the concept of unit operations first recognized by George E. Davis (although not by that name) [4] and first delineated by Arthur D. Little in 1915 [1]. MIT also developed the idea of intensive practical education through a graduate level practice school, but this innovation has not spread beyond MIT [1, 9].

Although there were programs in practical industrial chemistry before 1888, MIT was the first school to use the title chemical engineering [2]. After MIT, the University of Pennsylvania introduced a four-year chemical engineering program within chemistry in 1892 although a separate department was not established until 1951 [2]. In 1894 Tulane started the third curriculum in chemical engineering followed by University of Michigan and Tufts in 1898 and the University of Illinois-Urbana Champaign in 1901 [2]. The first independent chemical engineering departments in the US apparently were the University of Wisconsin in 1905 [2] and Purdue University in 1911 [10].

Curriculum Developments

Early curricula were often cobbled together from existing industrial chemistry and mechanical engineering courses, and it was common, as was the case at MIT, to have no courses labeled as chemical engineering [2]. As programs grew professors of chemical engineering were assigned and specific courses in chemical engineering were developed.

AIChE became involved in studying the education of chemical engineers in 1919 through its committee on Chemical Engineering Education [11]. Between 1921 and 1922 the committee, chaired by Arthur D. Little, studied the programs at 78 schools that claimed to teach chemical engineering, and decided that chemical engineering was based on the unit operations and involved industrial scale chemical processes [11]. Although controversial, the report of Little's committee was approved in 1922 and a new committee chaired by H. C. Parmelee was given three years to determine which programs were satisfactory. This report, with the names of 14 acceptable programs, was given in June, 1925, and constitutes the beginning of engineering accreditation in the US [11]. The Engineers' Council for Professional Development (now ABET) was formed in 1932. Since AIChE was the only engineering society involved in accreditation at that time, the Institute requested and received special status. One of these perks, that a copy of each ChE program's self-study report was to be provided to the AIChE committee, was not removed until the March 2008 meeting of the ABET Board of Directors [12].

In 1925 AIChE recommended that 10.3% of the curriculum be devoted to chemical engineering courses. The recommended amount of engineering has increased over the years. In 1938 15 to 20 % of the curricula was expected to consist of chemical engineering courses [13] (Table 1). Currently, ABET does not spell out the percentages of chemical engineering courses but focuses on the skills required by graduates [14, 15]. However, the total engineering percentage has increased [14] (Table 1).

It is interesting to consider the historical development of curricula. The curricula for Purdue University, which has always had a fairly typical curriculum, are shown in Table 2 [10]. While chemical engineering was still part of chemistry (1907-08), there were no courses identified as chemical engineering and German was required since much of the chemistry literature was published in German (Table 2). In addition, a thesis was required for graduation. This plan of study was truly a combination of industrial chemistry and mechanical engineering. An increase in military training occurred during the First World War. After chemical engineering became a separate department, separate ChE courses appeared and the industrial chemistry courses disappeared (1923-24 in Tables 2 and 3). Although still required, the amount of German decreased. Both the 1907-08 and 1923-24 plans of study required a modest amount of biology. The other engineering courses included electrical and mechanical engineering, plus surveying. Descriptive geometry, required in 1907 was dropped by 1923. The 1923-24 plan of study had insufficient chemical engineering courses to meet the recommendations of the AIChE Parmelee committee, and Purdue plus many other schools were not on the AIChE list of approved schools.

Purdue (and most other rejected schools) worked hard to satisfy AIChE requirements [10]. Purdue's 1936-37 plan of study (Tables 2 and 3) satisfied the AIChE recommendations (Table 1) and Purdue was first accredited in 1933. The 28 to 31 credits of chemical engineering shown for 1936-37 in Table 3 include 6 credits of metallurgy, which was part of chemical engineering. Biology was no longer required (the other science is mineralogy). The German requirement had been reduced to 6 credits and by 1950 disappeared entirely. By 1965, shop, mechanical drawing, additional science and German had all been eliminated. The military requirement was made semi-optional and the humanities requirement (elective with a few constraints) was increased significantly. Chemical engineering requirements were increased to 25% of the course load. The 1965-66 curriculum is fairly close to the "four-year compromise curriculum light in chemistry" discussed in 1969 by Morgen [13]. The proposed 2010-11 curriculum shows the inclusion of biology, an increase in chemical engineering courses including more design, and a significant increase in the amount of hands-on laboratory (1 credit each of Fluids, Heat & Mass Transfer, and Reactor Engineering are for laboratory). The molecular basis of ChE is taught in ChE, which only partially compensates for the reduction in chemistry. This proposed curriculum has two ChE electives, an additional engineering elective, and a technical elective. Several options such as pharmaceutical engineering allow students to use their electives in an organized fashion. The military requirement disappeared during the Vietnam War.

Although total credits have dropped through the years (Table 2), the student work load appears to have stayed constant or increased. The amount of chemistry in the curriculum (Table 2) has decreased significantly. Shop, German, mechanical drawing, mechanics, and military have slowly been phased out of the curriculum. Although still available, few students select these courses. Biology has done a boomerang and returned to the curriculum. Chemical engineering science courses replaced practical, but less scientifically oriented courses after World War II [16]. The percentage of chemical engineering courses has steadily increased and there has been a trend to move these courses earlier in the curriculum (Table 3). Although not obvious from Table 3 because of the years selected, the amount of design has oscillated back and forth and is currently waxing. Hougen's [17] analysis of the curriculum trends at the University of Wisconsin are similar to those shown here, except that Wisconsin was often several years ahead of Purdue in making changes.

The current ChE curriculum at Purdue and most schools is extremely hierarchical. Starting with the first calculus course, Purdue has a seven semester sequence of required courses to graduation consisting of the calculus courses and differential equations which is a co-requisite for fluids which is followed by heat & mass transfer, which is a co-requisite for the first of two ChE labs. There are also several four semester sequences of ChE courses starting with mass and energy balances. Few of the other engineering programs have prerequisite requirements as strict.

A long term change not readily evident from looking at curricula is who teaches chemical engineering. Initially, there were no chemical engineers and the courses were usually taught by chemists and mechanical engineers. Once chemical engineers had graduated and were available to become professors, most of the chemical engineering professors had significant industrial experience and rarely had a Ph.D. [6]. Over the years an earned Ph.D. became a requirement and the expectation that engineering professors would have practical experience was lost. The current lack of practical understanding of industry and the practice of chemical engineering is obviously a problem in the education of undergraduate chemical engineers [18, 19]. The current interest in rewarding research makes it unlikely that this lack will be solved in the near future.

Current Curriculum Developments

There have been a number of recent efforts at national curriculum reform. The University of Texas-Austin Septenary committee did a major analysis of the curriculum in the early 1980's [20, 21]. The committee recommended the following: an overhaul of all the ChE courses to strengthen fundamentals and include computer calculations in all courses; inclusion of modern biology, economics and business courses in the curriculum; sufficient electives to allow specialization; and an overhaul of teaching methods and tools including major revisions of all the textbooks. The recommendations of the Committee to provide incentives for rewritting textbooks have been ignored, but many of the other recommendations made by the Septenary committee were adopted at Texas. The report also had some impact elsewhere. In particular, the need to integrate biology and chemistry into the curriculum has been widely understood [22, 23]. The need for options or tracks, which had been recommended previously [24], does not appear to have been widely adopted. The current University of Texas-Austin curriculum [25] differs from Purdue's

(Tables 2 and 3) by specifying humanities electives in American History and American Government, and requiring a literature course. In addition, an electrical engineering course is required and there are a total of six electives in science, technical and engineering areas compared to the four electives in these areas at Purdue. Both programs now require biology. Thus, the differences in these two curricula are rather small.

There has also been a push to focus chemical engineering education more on product engineering because the structure of the chemical industry has changed markedly. Many chemical engineers at both the bachelors and the Ph.D. levels now work for companies that are not considered to be chemical companies [19, 26-29], and the world of chemical engineering continues to expand [30]. Many more chemical engineers will work in specialty chemicals instead of commodity chemicals. These shifts will require more chemistry, in particular structure-property relationships including the use of quantum mechanical software. Graduates will need to be comfortable with producing products that function based on their micro- or nano-structure. In addition, there will be more interest and need to teach batch processing. Our examples and textbooks need to be revised to include examples from a much wider variety of industries. Some detailed examples of product design are available [28, 29]. At least from course titles, product design does not appear to have become a required course at MIT [31], Purdue (Table 3), University of Minnesota [32] or University of Texas-Austin [25]. Perhaps professors are including product design as examples in their courses.

Another current curriculum revision initiative is called the Frontiers in Chemical Engineering Education Initiative [33-36] that started with meetings in 2002. The initiative looks to: 1. Integrate biology into the curriculum, 2. Balance the diversity of research areas with a strong undergraduate core, 3. Balance applications and fundamentals, 4. Include both process and product design, and 5. Attract the best students to ChE. The initiative proposes that the organizing principles of chemical engineering are molecular transformations, systems and multiscale analysis. The new curriculum is supposed to be integrative and include the organizing principles plus laboratory experiences, examples, teaming and communication skills throughout the course sequence. Unfortunately, most popular chemical engineering textbooks are not arranged around the proposed organizing principles and little material for teaching within this curriculum is available. Although the initiative has been led from MIT, the current MIT curriculum [31] does not reflect this initiative. To be successful this initiative will have to convince professors that the changes are necessary, train professors in new pedagogy, and sponsor the development of an enormous amount of teaching material. In a related effort that was started independently, the chemical engineering professors at the University of Pittsburgh appear to have been convinced that these changes are necessary since Pitt has instituted a "Pillars of Chemical Engineering" curriculum [36-39]. The six "Pillar" courses on Foundations, Thermodynamics, Transport, Reactive Processes, Systems & Dynamics, and Design are block scheduled to provide additional time. The courses include molecular insight and modeling, product design, multiscale analysis, and a significant amount of simulations. Preliminary assessment data with concept maps and concept inventories shows that students are learning concepts better with the new curriculum [38, 39].

Textbooks and Other Teaching Materials

"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." [40, p. 185] In addition to Walker, Lewis and McAdams [8] Professor Bird [40] cited the books by Hougen and Watson [41], and Hougen, Watson and Ragatz [42, 43] as particularly influential. We can certainly add Badger and McCabe [44] and many other books to this list. The McGraw-Hill series of chemical engineering books started in 1925 was also very important for a number of years. Although not a textbook, Perry's Handbook [45], first published in 1934 with significant contributions from DuPont chemical engineers, has also been quite influential in chemical engineering education.

Textbooks can both constrain and open a discipline [21]. For example, BSL [46] clearly helped open chemical engineering to a more scientific approach, but later helped constrain the discipline to a continuum approach. Extremely popular textbooks such as Felder and Rousseau [47] and Fogler [48] serve to standardize parts of the ChE curriculum across the country since the vast majority of students have used these books. Because they are so widely used, the popular books can enhance or impede curriculum changes depending on the interests of the authors.

One of the current problems in chemical engineering education is, with very few exceptions, there are no young textbook authors. The first edition of most of the current ChE textbooks were written when the author(s) were in their 40s or 50s, and many of these texts are in the 2nd, 3rd, or higher editions. Younger professors are more likely to be trained in new content that should be worked into the curriculum. Unfortunately, standard advice for untenured professors is to *not* write a textbook [21, 40, 49, 50]. Professor Bird also advises, "Book-writing should not be undertaken to gain fame and fortune." [40] Although a successful textbook can pay for the college education of the author's children, the other rewards are seldom commensurate with the effort required to write a good book [40, 50]. Most chemical engineering professors are not trained in pedagogy and a really good textbook has to be based on sound learning principles in addition to being technically correct. The soundness of the pedagogical approaches is one reason for the successes of Felder and Rousseau [47] and Fogler [48]. Training all professors how-to-teach [49] would reduce the amount of on-the-job-training in writing textbooks. There have been calls for more rewards for writers of textbooks [21, 35, 40], but so far action has been sparse.

There have been attempts to use other materials besides textbooks for presenting teaching material. In the 1980's AIChE developed a series of six volumes of Modular Instruction (AIChEMI) under the overall direction of Prof. E. J. Henley. The six volumes covered Kinetics, Mass and Energy Balances, Process Control, Stagewise and Mass Transfer Operations, Thermodynamics and Transport. Modules had the advantage that the effort to write a module was orders of magnitude less than writing a textbook. Unfortunately, the quality was erratic and the modules were not widely adopted. The effort has apparently disappeared since none of the modules appears in the current AIChE catalog.

Computer aided instruction and educational games have enormous potential for improving technical education [50-53] particularly for students in the gamer generation [52]. Some of the leading ChE textbooks [e.g., 47, 48] provide supplemental instructional software as either a CD bundled with the textbook or as a course web page. Unfortunately, students often do not use the supplemental material even when required to do so [54]. Instructional games have considerable promise [53], but with current technology developing a professional quality educational game takes an order of magnitude or more effort than producing a textbook. The chemical engineering market is not large enough to support these efforts without subsidies. A major reduction in the time and cost required to develop instructional games is necessary before educational games can become economically viable to teach chemical engineering material. However, chemical engineering students may use these methods to learn calculus, chemistry [53], physics, biology, economics, and other large enrollment subjects.

Pedagogical Developments in Chemical Engineering

Since the other presentations in this symposium will discuss teaching methods in detail, I will only briefly highlight teaching methods and the contributions of ChE professors to improve teaching. Similar to all fields [50], ChE professors lecture much of the time in class. Their teaching would improve if they heeded the oft-given advice, *"Lecture less."* Instead of lecturing they could use various active and inductive learning methods such as cooperative group learning, "clickers," guided design, problem based learning, quizzes, laboratory improvements and hands-on learning, and computer simulations for part or all of the class periods [50, 55-66]. Chemical engineering professors have also been at the forefront of activities to make ABET requirements for assessment more meaningful [67, 68]. A paradox is that chemical engineering professors such as John Falconer, Rich Felder, Ron Miller, Mike Prince, Joe Shaeiwitz, Jim Stice, Charlie Wales, Phil Wankat, Don Woods, Karl Smith (an honorary ChE since his BS and MS degrees were in process metallurgy), and the entire ChE faculty at Rowan University have been at the forefront of developing and popularizing these techniques, but most ChE professors do not use them.

Chemical engineers have also been at the forefront of helping professors learn how-to-teach [49, 69-70]. The once every five years Chemical Engineering Summer School has included a how-to-teach workshop since 1987, and the popular and successful ASEE National Effective Teaching Institutes are led by chemical engineers. In addition, the Chemical Engineering Division of ASEE publishes the highly respected journal *Chemical Engineering Education* which covers new chemical engineering content and how to improve teaching and learning in chemical engineering. Teaching interested attendees to be better teachers is effective [69, 70] and it is relatively easy. Yet, it is doubtful that the majority of ChE professors have attended a formal teaching workshop or teaching course. In the past teaching workshops and courses for engineering professors were not readily available, and the reward structure at most universities did not strongly encourage faculty to improve their teaching. In my opinion *the single most effective action that can be taken to improve engineering education is to require all new engineering professors and encourage current engineering professors to take a course in how-to-teach*.

Research in improving engineering education has very recently become much more popular. This is signaled by the increased attention paid to this research by ASEE and the National Academy of Engineering, the tightening of publication requirements by the *Journal of Engineering Education* [71], the emergence of engineering education as a separate research field [72], and the development of new engineering education Ph.D. programs [73]. Chemical engineers have been at the forefront of many of these efforts. Because most engineering professors are not trained to do rigorous educational research, NSF has sponsored workshops to help interested professors start learning how to do rigorous educational research [74].

Closure

Chemical engineers active in improving engineering education are often asked why chemical engineering, which is not one of the larger engineering disciplines, has had a large impact on engineering education. I will close by speculating on the answer. Chemical engineers are interested in processes while most engineering disciplines have focused on products. Teaching and learning are processes. Thus, it is natural that chemical engineers would contribute to improving these processes. The other major engineering field interested in processes, albeit of a different type, is industrial engineering. Industrial engineering has been at the forefront of graduating Ph.D.s who did their research on engineering education. I believe that their interest in processes is a major reason that chemical engineers have been and will continue to be leaders in engineering education.

References

1. Weber, H. C., "The Improbable Achievement: Chemical Engineering at MIT," in Furter, W. F. (Ed.), *History of Chemical Engineering,* Washington, D.C., American Chemical Society, *Advances in Chemistry Series*, **190**, 77-96 (1980)
2. Westwater, J. W., "The Beginnings of Chemical Engineering Education in the United States," in Furter, W. F. (Ed.), *History of Chemical Engineering,* Washington, D.C., American Chemical Society, *Advances in Chemistry Series*, **190**, 140-152 (1980)
3. Van Antwerpen, F. J., "The Origins of Chemical Engineering," in Furter, W. F. (Ed.), *History of Chemical Engineering,* Washington, D.C., American Chemical Society, *Advances in Chemistry Series*, **190**, 1-14 (1980)
4. Davies, J. T., "Chemical Engineering: How Did it Begin and Develop?" in Furter, W. F. (Ed.), *History of Chemical Engineering,* Washington, D.C., American Chemical Society, *Advances in Chemistry Series*, **190**, 15-43 (1980)
5. Furter, W. F. (Ed.), *History of Chemical Engineering,* Washington, D.C., American Chemical Society, *Advances in Chemistry Series*, **190**, (1980)
6. Williams, G. C. and J. E. Vivian, "Pioneers in Chemical Engineering at MIT," in Furter, W. F. (Ed.), *History of Chemical Engineering,* Washington, D.C., American Chemical Society, *Advances in Chemistry Series*, **190**, 113-128 (1980)
7. Robinson, C. S., *Elements of Fractional Distillation,* McGraw-Hill, New York, 1922.
8. Walker, W. H., W. K. Lewis and W. H. McAdams, *Principles of Chemical Engineering*, McGraw-Hill, New York, 1923.
9. Johnston, B. S., T. A. Meadowcroft, A. J. Franz, and T. A. Hatton, "The MIT Practice School," *Chem. Engr. Educ., 28* (1), 38 (Winter 1994).
10. Peppas, N. A., *History of the School of Chemical Engineering of Purdue University,* West Lafayette, IN, School of Chemical Engineering, Purdue University, 1986.
11. Reynolds, T. S., *75 Years of Progress – a History of the American Institute of Chemical Engineers 1908-1983,* New York, AIChE, 1983.
12. ABET Report of the Board, http://www.abet.org/board_report.shtml Accessed June 20, 2008.
13. Morgen, R. A., "The Chemistry-Chemical Engineering Merry-Go-Round," *Chem. Engr. Educ., 3* (4), 228 (Fall 1969).
14. http://abet.org/, ABET (2007), "Criteria for Accrediting Engineering Programs. Effective for Evaluations During the 2008-2009 Accreditation Cycle," accessed 28 April, 2008.
15. Rugarcia, A., R. M. Felder, D. R. Woods, and J. E. Stice, "The Future of Engineering Education. Part 1. A Vision for a New Century," *Chem. Engr. Educ., 34* (1), 16 (Winter 2000).

16. Seely, B. A., “The Other Re-engineering of Engineering Education, 1900-1965,” *J. Engr. Educ., 88* (3), 285 (July 1999).
17. Hougen, O. A., “Seven Decades of Chemical Engineering,” *Chem. Engr. Prog.,* 73 (1), 89 (January 1977).
18. Landau, R., “The Chemical Engineer – Today and Tomorrow,” *Chem. Engr. Prog., 68* (6), 9 (June 1972).
19. Shinnar, R., “The Future of Chemical Engineering,” *Chem. Engr. Prog., 87* (9), 80 (Sept. 1991).
20. 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).
21. Sciance, C. T., “Chemical Engineering in the Future,” *Chem. Engr. Educ.,* (4), 12 (Winter 1987).
22. Westmoreland, P. R., “Chemistry and Life Sciences in a New Vision of Chemical Engineering,” *Chem. Engr. Educ., 35* (4), 248 (Fall 2001).
23. 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* (1), 43 (Winter 2007).
24. Felder, R. M., “The Future ChE Curriculum. Must One Size Fit All?” *Chem. Engr. Educ., 21* (2), 74 (Spring 1987).
25. Chemical Engineering 2006-2008 Catalog, University Texas-Austin, http://www.utexas.edu/student/registrar/catalogs/ug06-08/ch06/courses/ch0602che-ce.html Accessed May 27,2008.
26. Cussler, E. L., D. W. Savage, A. P. J. Middelberg, and M. Kind, “Refocusing Chemical Engineering, *Chem. Engr. Prog., 98* (1), 26S (January 2002).
27. Cussler, E. L. and J. Wei, "Chemical Product Engineering," *AIChE J., 49*, 1072-1075 (2003).
28. Cussler, E. L. and G. D. Moggridge, *Chemical Product Design*, Cambridge University Press, 2001.
29. Ng, K. M., R. Gani, and K. Dam-Johansen (Eds.), *Chemical Product Design. Towards a Perspective through Case Studies,* Elsevier, Amsterdam, 2007.
30. Furusaki, S., J. Garside, and L. S. Fan (Eds.), *The Expanding World of Chemical Engineering,* 2nd Edition, Taylor & Francis, New York, 2002.
31. Massachusetts Institute of Technology, Chemical Engineering curriculum, http://web.mit.edu/afs/athena.mit.edu/org/c/catalogue/degre.engin.ch10.shtml, Accessed June 18, 2008.
32.University of Minnesota, Chemical Engineering curriculum, http://www.cems.umn.edu/academics/chen/index.php Click on “Typical Plan for 2011 or later grads (pdf)” Accessed June 18, 2008.
33. Cobb, J. T. Jr., G. K. Patterson, and S. R. Wickramasinghe, “The Future of Chemical Engineering – An Educational Perspective,” *Chem. Eng. Prog., 103* (1), 30S (January 2007).
34. Armstrong, R. C., “A Vision of the Curriculum of the Future,” *Chem. Engr. Educ., 40* (2), 104 (Spring 2006).
35. Frontiers in Chemical Engineering Education Initiative, http://mit.edu/che-curriculum/ Accessed May 27, 2008.
36. “Pillars of Chemical Engineering: A Block-Scheduled Engineering Curriculum,” University of Pittsburgh, http://granular.che.pitt.edu/curriculum/, Accessed July 2, 2008.
37. McCarthy, J. J. and R. S. Parker, “Pillars of Chemical Engineering: A Block-Scheduled Curriculum,” *Chem. Engr. Educ., 38* (4) 292 (Fall 2004).

38. McCarthy, J. J., A. A. Abatan, R. S. Parker and M. Besterfield-Sacre, "Work In Progress: Pillars of Chemical Engineering," Proceedings ASEE/IEEE Frontiers in Education Conference, Indianapolis, IN, Session F3H (Oct. 2005).
39. McCarthy, J. J., R. S. Parker and M. Besterfield-Sacre, "Results and Dissemination Plans of the Pillars Curriculum at Pittsburgh," ASEE Meeting, Philadelphia (June 2008).
40. Bird, R. B., "Book Writing and Chemical Engineering Education. Rites, Rewards, and Responsibilities," *Chem. Engr. Educ., 17* (4), 184 (Fall 1983).
41. Hougen, O. A. and K. M. Watson, *Kinetics and Catalysis,* Wiley, New York, (1947).
42. Hougen, O. A., K. M. Watson, and R. A. Ragatz, *Material and Energy Balances,* Wiley, New York, (1954).
43. Hougen, O. A., K. M. Watson, and R. A. Ragatz, *Thermodynamics,* Wiley, New York, (1959).
44. Badger, W. L. and W. L. McCabe, *Elements of Chemical Engineering,* McGraw-Hill, New York (1931).
45. Perry, J. H. (Editor-in-Chief), *Chemical Engineers' Handbook,* McGraw-Hill, New York (1934).
46. Bird, R. B., W. E. Stewart, and E. N. Lightfoot, *Transport Phenomena*, Wiley, New York (1960).
47. Felder, R. M. and R. W. Rousseau, *Elementary Principles of Chemical Processes,* 3rd update edition, Wiley, New York (2004)
48. Fogler, H. S., *Elements of Chemical Reaction Engineering,* 4th Edition, Prentice-Hall (2005).
49. Wankat, P.C. and Oreovicz, F.S., *Teaching Engineering*, McGraw-Hill, NY (1993). Available free https://engineering.purdue.edu/ChE/AboutUs/Publications/TeachingEng/index.html
50. Wankat, P. C., *The Effective, Efficient Professor. Teaching, Scholarship and Service*, Allyn & Bacon, Boston (2002).
51. Kadiyala, M. and B. L. Crynes, "A Review of Literature on Effectiveness of Use of Information Technology in Education," *J. Engr. Educ., 89,* 177 (2000).
52. Beck, J. C. and M. Wade, *Got Game. How the Gamer Generation is Reshaping Business Forever,* Harvard Business School Press, Boston, 2004.
53. Rovner, L. L., "Video Game Aims to Engage Students," *Chem. & Engr. News,* 84, p. 76, (April 10, 2006).
54. Roskowski, A. M., R. M. Felder, and L. G. Bullard, "Student Use (and Non-Use) of Instructional Software," *J. SMET Education, 2* (3&4), 41 (Sept-Dec, 2001).
55. Felder, R. M., D. R. Woods, J. E. Stice, and A. Rugarcia, "The Future of Engineering Education. Part 2. Teaching Methods that Work," *Chem. Engr. Educ., 34* (1), 26 (Winter 2000).
56. Prince, M. J., "Does Active Learning Work? A Review of the Research," *J Engr. Educ., 93* (3), 223 (2004).
57. Prince, M. J. and R. M. Felder, "Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases," *J Engr. Educ., 9* (2), 123 (2006).
58. Newell, J. A., "Survivor: Classroom – A Method of Active Learning that Addresses Four Types of Student Motivation," *Chem. Engr. Educ., 39* (3), 228 (Summer 2005).
59. Johnson, D. W., R. T. Johnson, and K. A. Smith, "Cooperative Learning Returns to College: What Evidence is There That It Works?" *Change, 30* (4), 27 (1998).
60. Woods, D. R., *Problem-Based Learning: How to Gain the Most from PBL,* Donald R. Woods, Waterdown, Ontario (1994).
61. Wales, C. E., R. A. Stager, and T. R. Long, *Guided Engineering Design,* West Publishing Company, St. Paul, MN (1974).
62. Dahm, K. D., "Process Simulation and McCabe-Thiele Modeling: Specific Roles in the Learning Process," *Chem. Engr. Educ., 37* (2) 132 (Spring 2003).

63. Wankat, P. C., “Using a Commercial Simulator to Teach Sorption Separations,” *Chem. Engr Educ., 40*, 165-172 (2006).
64. Falconer, J. L., “Conceptests for a Thermodynamics Course,” *Chem. Engr. Educ., 41* (2), 107 (Spring 2007).
65. Dahm, K. D., R. P. Hesketh, and M. J. Savelski, “Micromixing Experiments in the Introductory Chemical Reaction Engineering Course,” *Chem. Engr. Educ., 39* (2), 94 (Spring 2005).
66. Farrell, S., M. J. Savelski and R. Hesketh, “Energy Balances on the Human Body: A Hands-on Exploration of Heat, Work, and Power,” *Chem. Engr. Educ., 39* (1), 30 (Winter 2005).
67. Olds, B. M., B. M. Moskal, and R. M. Miller, “Assessment in Engineering Education: Evolution, Approaches and Future Collaborations,” *J. Engr. Educ., 94* (1), 13 (Jan. 2005).
68. Shaeiwitz, J. A., “Teaching Design by Integration throughout the Curriculum and Assessing the Curriculum using Design Projects,” *International Journal of Engineering Education*, *17*, 479 (2001).
69. Stice, J. E., R. M. Felder, D. R. Woods, and A. Rugarcia, “The Future of Engineering Education: Part 4, Learning How to Teach,” *Chem. Engr. Educ., 34* (2), 118 (Spring 2000).
70. Wankat, P. C., and F. S. Oreovicz, “Teaching Prospective Engineering Faculty How To Teach,” *Intl. J. Engr. Educ., 21* (5) 925-930 (2005).
71. Lohmann, J. R., “Editor’s Page: Refining our Focus,” *J. Eng. Educ.,* **97** (1), 1 (2008).
72. Haghighi, K., K. A. Smith, B. M. Olds, N. Fortenberry, and S. Bond, “Guest Editorial: The Time is Now: Are We Ready for Our Role?” *J. Engr. Educ., 97* (2), 119 (April 2008).
73. Wankat, P. C., Pedagogical Training and Research in Engineering Education,” *Chem. Engr Educ., 42* (4), (Fall 2008).
74. Streveler, R. A. and K. A. Smith, “Guest Editorial: Conducting Rigorous Research in Engineering Education,” *J. Eng. Educ.,* **95** (2) 103 (2006).

Table 1. Accreditation Recommended % in ChE Curricula [13, 14]

Topic	AIChE 1938 [13]		Topic	ABET 2008-2009 [14]
Chemistry	25-30%		Math & Basic Science	25% minimum Sufficient material to be consistent with objectives
Math	12%			
Physics	8%			
Other Sciences	2%			
Mechanics	6%			
Chemical Engineering	20-15%		Engineering	37.5% Must include design & sufficient material to be consistent with objectives
Other Engineering	12%			
Cultural Subjects	15%		General Education	Complement other components & consistent with objectives
Total	~148 credits			~124 or more credits

Table 2. ChE Plans of Study at Purdue University [10].

Topic	1907-08	1923-24[2]	1936-37[3]	1965-66	Proposed 2009-10
Chemistry	15.1%	23.7-29.9%	24.2-26.9%	16.7%	14.5%
Math	16.8%	12.3%	11.8%	12.5%	14.5%
Physics	6.6%	4.9%	5.3%	8.3%	5.3%
Other Science	1.0%	1.2-3.1%	2.0%	-----	2.3%
Mech. Draw	3.0%	2.5%	2.6%	------	-----
Mechanics	4.4%	4.9%	7.9%	2.1%	------
Ind. chem/tech	11.0%	----	---	---	-----
Chem Engr.	----	6.7-10.4%	18.3-20.3%	25.-25.7%	36.6%
Other Engr.	12.6%	12.3-19.0%	5.2%	8.3%	5.3%
Shop	7.0%	2.5%	2.6%	-------	-----
Tech electives	----	----	-----	4.9-5.6%	2.3%
Military	3.0%	3.9-13.1%	4.4%	0-5.6%	-----
English/speech	5.6%	3.7%	5.9%	3.5%	5.3%
German	10.0%	7.4-9.2%	3.9%	----	----
Other humanities	3.8%	5.5%	2.0%	12.5%	13.7%
Other	---	---	2.0%	5.6-0%	-----
Total Credits	398.5 pts[1]	163[3]-169 cr	152.7[4]-154.7	144 cr	131 cr

[1] 1 point for each hour per week in courses with no outside work and 2.5 points for each hour per week in courses with outside work. [2] Depends on options chosen. The 163 minimum was used to determine %. [3] Depends on options. The 152.7 minimum was used to determine %.

Table 3. Chemical Engineering Courses at Purdue University [10]

Semester	1907-08	1923-24	1936-37[1]	1965-66	Proposed 2010-11
1	None	None	None	None	None
2	None	None	ChE/Met, 3. (Optional)	None	None
3	None	None	None	ChE Calc, 3	ChE Calc, 3
4	None	None	None	Intro Chem Proc Ind., 3	Thermo, 4 Stat Model, 3
5	None	None	None	Thermo, 3. Fluids & Heat Trans,4	Separation, 3 Fluids, 4
6	None	Thermo, 3cr	Thermo, 3. Elem. Unit Ops, 2	Mass Transfer, 4 ChE Lab, 2	Heat/Mass Transfer, 4 Rx Eng, 4 Molec Eng, 3
7	Indus. Chem & Tech Anal, 22 points	Elements ChE I, 3. Metallurgy, 3 (Optional)	Elem. Unit Ops, 2 Unit Ops, 3 Non-Ferrous Metallurgy, 3 Pyrometry, 2 Plant Des, 2 ChE Prob, 1	Rx Kinet, 3 ChE Lab, 2 Prof. Guid. & Inspection Trips, 1 ChE Elec 3-4	ChE Lab I, 3 Proc. Dynam. & Control, 3 Des & Cost Anal., 3 ChE Elec., 3
8	Indus. Chem & Tech Anal, 22 points	Elements ChE II, 3. Metallurgy, 3 (Optional)	Inorg & Org Techn & Stoich, 3 Unit Ops, 3 Ferrous Metall., 3 ChE Prob., 1	Proc. Dynam & Control, 3 Proc. Des & Economics, 3 ChE Elec., 3	ChE Lab II, 3 Proc. Des, 2 ChE Elec., 3
Total	44 points	9-15 cr.	28-31 cr.	36-37 cr.	48 cr.

[1] Shown for the General Chemical Engineering program (Other options were Gas Technology, Metallurgy, Military, and Organic Technology).