CURRENT TRENDS IN CHEMICAL REACTION ENGINEERING EDUCATION

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Chemical engineering is a practical specialization combining several fundamental scientific disciplines within the field of engineering in order to solve the problems and challenges facing mankind. It evolved around the beginning of this century in response to the world's increasing industrialization. Required courses for chemical engineering majors almost universally include a sequence of multidisciplinary courses. Chemical reaction engineering (CRE), the study of the basic knowledge of chemical kinetics and reactor design, is the most important area of study and is the main area that distinctly characterizes chemical engineering from other engineering disciplines.

CRE also uses areas (such as thermodynamics, transport phenomena, and other related disciplines) in analyzing small- and large-scale reaction systems. In a recent article, Doraiswamy[1] addressed the fact that students majoring in CRE not only must have a proper background in the fundamentals (such as ideal reactor design), but they should also tackle new and challenging areas, such as biochemical, microelectronic, polymer, and electrochemical reaction engineering. He also stressed the importance of CRE education as a possible "interdisciplinary single umbrella" to cover all these different disciplines. If one basic course is not enough, Savage and Blaine[2] have proposed that additional elective courses should be introduced to cover these areas.

Another important CRE area is catalysis, especially heterogeneous catalysis—it has evolved as a consequence of the widespread use of the many catalytic reaction systems in industry and is not usually covered in depth in engineering courses. Heterogeneous catalysis courses and their importance in engineering education have been reviewed by Vannice[3] and Miranda.[4] They combined the traditional material of catalysis with the more advanced knowledge of solid state, surface chemistry, and material processing, such as sol-gel technology and chemical vapor deposition.

A more thorough review of CRE education can be found in an article by Dudukovic[5] comparing the results of a 1982 AIChE survey of CRE courses in US and Canadian chemical engineering departments with a similar study completed by Eisen[6] in the early 1970s.

This article reports the results obtained from a similar survey, conducted during the first part of 1993, that involved more than a hundred chemical engineering departments worldwide. Recent trends in CRE related to type of courses offered, teaching material, and textbooks used on both undergraduate and graduate levels, will be compared with the results of Dudukovic's previous survey.

QUESTIONNAIRE DESIGN AND ANALYSIS

The main objective of the survey was to determine what is taught as CRE at both the undergraduate and the graduate level in chemical engineering departments in North and South America, Europe, the Middle East, Asia, and Australia. A questionnaire was designed that included two main streams of questions: the first part consisted of eight questions and was primarily concerned with teaching and organization of the undergraduate and graduate courses; the second part dealt principally with the main and reference textbooks and the level of satisfaction with current teaching material, including the type of PC software packages. At the end of the questionnaire the departments were asked to give their perception of the

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future of CRE education for the next ten years.

A total of 137 questionnaires were sent out: 58 to U.S. chemical engineering departments and 79 to the other world areas mentioned above. The response rate was roughly 69%, with returns from 40 US departments and 55 from the other countries.

COURSE CONTENT

Figure 1a shows the number of CRE courses available for undergraduate students. The majority of schools have only one compulsory course (66%) while only 35% have at least one elective undergraduate course. This finding is similar to Dudukovic's survey of thirteen years ago showing that 69% of the schools had at least one CRE course available. On the other hand, Figure 1b shows that 42% of the schools have only one compulsory course for graduate students, compared to 64% thirteen years ago.

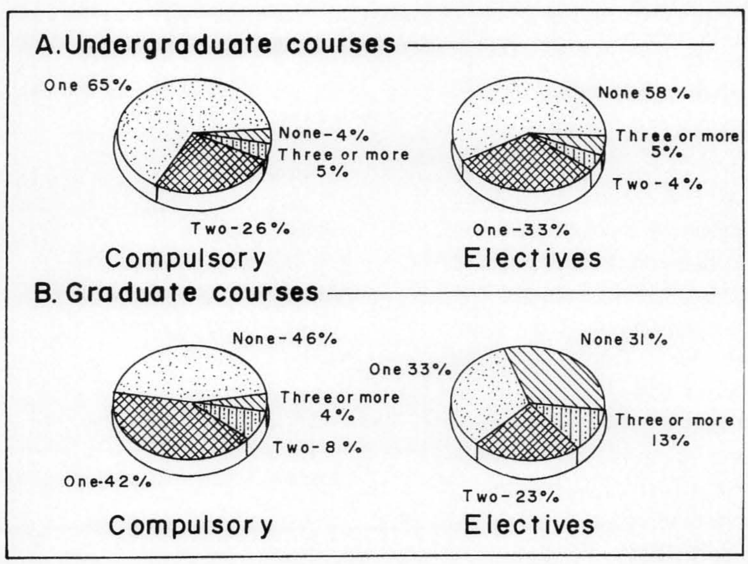

Figure 1a,b. Number of CRE courses available for undergraduate and graduate students.

Figure 2 compares the distribution of undergraduate CRE courses (compulsory and elective) with the geographical distribution of the chemical engineering departments around the world. A very different distribution can be seen in the case of compulsory courses (Figure 2a). In the US, nearly 90% of the schools have one compulsory course, while in the United Kingdom practically all the schools have two compulsory courses. A similar trend is observed in Asian countries, with 77% of the schools having two compulsory courses. On the other hand, nearly 20% of the continental European schools do not have compulsory courses at all. For the other regions (Middle East, Canada, Australia, New Zealand, and South America), the course distribution is between one and two compulsory courses, ranging from a minimum of 30% (Middle East) to a maximum of 75% (Canada) for one compulsory course. With reference to elective courses, the figure shows that with the exception of South American countries, there is an average tendency of 50% for not offering an elective course in CRE, with a minimum of 25% for Asian countries and a maximum of 80% for the United Kingdom.

With regard to the average class size for undergraduate courses, most of the departments (51%) have classes of forty or more students (see Figure 3a), while only 5% have classes of less than twenty students. The majority of departments (75%) offer two to three hours of lecture per week (see Figure 3b), but it is important to note that 51% have less than two hours tutorial/problem solving per week, as shown in Figure 3c. Figure 3d summarizes the answers to a question regarding the number of laboratory experiments:

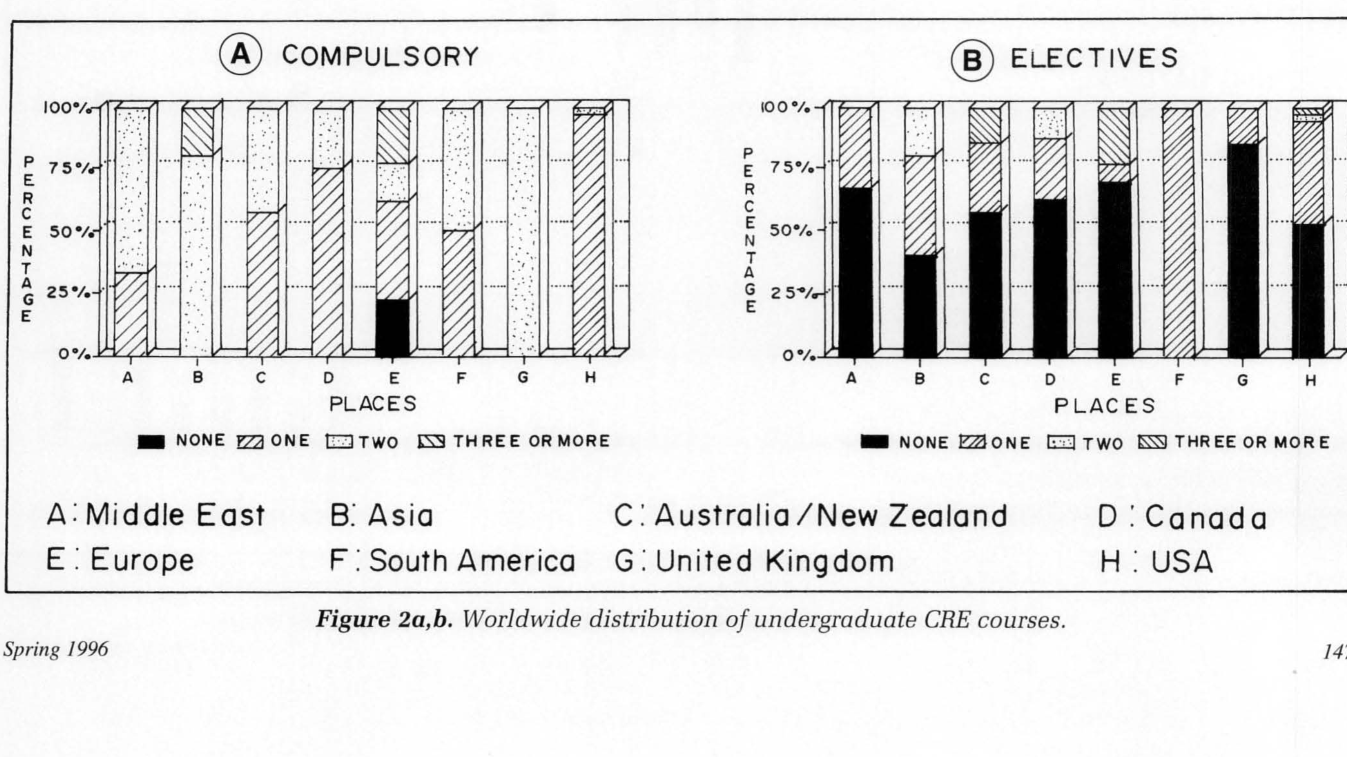

Figure 2a,b. Worldwide distribution of undergraduate CRE courses.

it can be seen that only 12% of the departments require at least one experiment during the teaching of the CRE course, and that 46% of the departments have no laboratory experiment.

Figure 4 compares class structure as a function of geographical distribution of the schools. Regarding class size, two well-defined groups were observed. One group, the Middle East and South American countries, have small classes (up to thirty), while the rest of the world accomodates larger classes (forty or more). Concerning time spent on lectures during the week, Figure 4b shows equal distribution for all locales, with two to three hours a week devoted to lectures. But there is ample disparity in the time distribution for tutorials per week as well as in the number of experiments performed, as can be seen in Figures 4c and 4d, respectively. Analysis of the data concerning the number of experiments performed (Figure 4d) shows that 70% of all the Middle East and US schools do not have experiments, but that 25% of the South American schools have at least one experiment.

Table 1 summarizes the basic concepts covered during the undergraduate course. Kinetics and mechanism, along with interpretation of kinetic data, are regarded as the most important concepts by 54% of the schools, followed by ideal reactor design and catalytic reactor design, by 46% and 43%, respectively. Only 23% of the schools ranked the importance of non-ideal reactors. In general, the different departments expressed that homogeneous systems receive more attention than heterogeneous systems, but as many as 18% of the departments do not cover heterogeneous systems at all in the compulsory undergraduate CRE. As far as industrial input is concerned, 32% of the departments claimed it as a very important part of the course.

TEACHING MATERIAL AND RECOMMENDED TEXTBOOKS

Table 2 shows the textbooks used for both undergraduate and graduate CRE courses. Eleven known textbooks were listed in the survey.[7-17] For undergraduate courses, Fogler's textbook is the most popular, presently used by 41% of the schools. This replaced Levenspiel's textbook, written 23 years ago, that once enjoyed a popularity of 58% but which is presently used by only 25.3% of the departments. It is interesting to note that nearly 10% of the departments use their own textbook. They claimed that this allows them to properly match the CRE undergraduate curriculum with their time and place needs. The main reason cited for the change to Fogler's textbook was his structured approach to teaching CRE that involves problem solving and decision making techniques. Some of the departments also cited the material covering the emerging areas (microelectronics, biotechnology, and polymerization reactions) as a reason for changing. Still another reason for the change was the use of computer software in solving the prescribed textbook exercises.

For graduate courses, Froment and Bischoff's textbook is the most popular (33.7%), while nearly 27.3% of the schools actually produce their own teaching material. Most of the instructors (92% undergraduate,

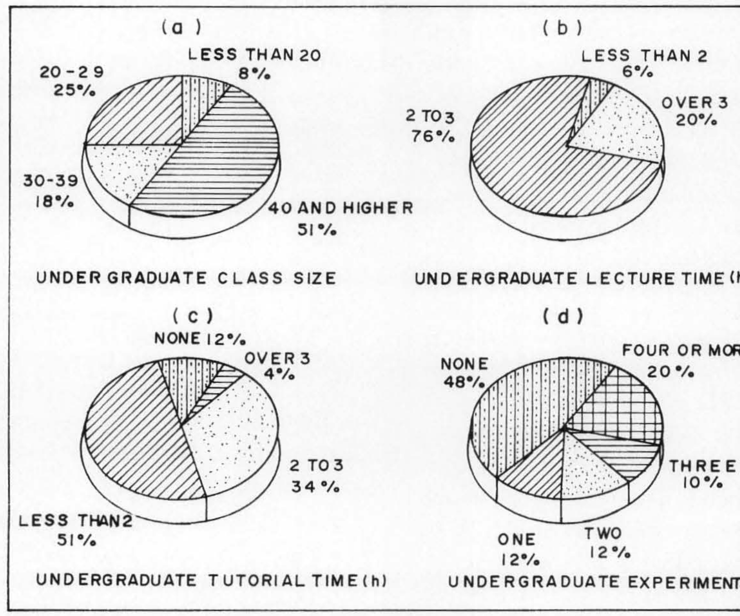

Figure 3. *Class structure on undergraduate courses.*

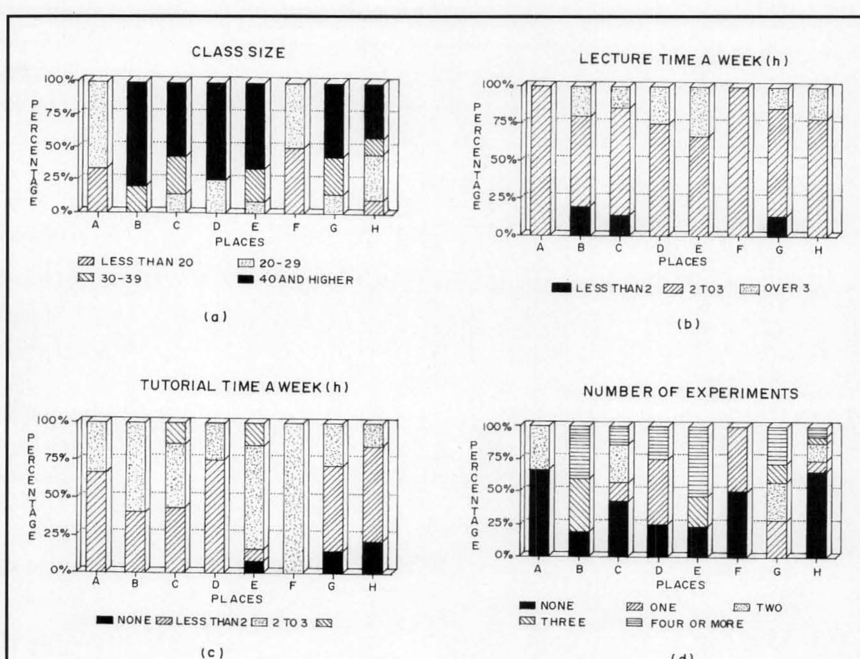

Figure 4. *Class structure as a function of geographical distribution of the schools.*

83% graduate) view their present textbook is satisfactory. Forty-four percent changed their textbook in the last five years, but only 25% of undergraduate and 18% of graduate courses are considering a change in the next two years.

Concerning development of software material for problem solving, 60% of the departments have developed or purchased computer software made available through main frame and personal computer facilities. The distribution by regions shows very clearly that in the case of US and Canada, 66% of the schools adopted this approach, while only 15% of the schools in Australia, New Zealand, South America, the Middle East, and Asia adopted it. In Europe and the United Kingdom, the percentage of positive answers was nearly 50%. The types of software ranged from commercial mathematical programs (such as Polymath and Mathematica) to more sophisticated software.

CURRENT AND FUTURE TRENDS

In answer to a question relating to the future of CRE courses in the next ten years, the following were the main points addressed by the departments:

TABLE 1
Course Dedication to Various Key Concepts in CRE

Topics	Very Important	Important	Average	Not Important
Kinetics and mechanisms	54	28	15	3
Interpretation of kinetic data	54	33	13	-
Reactor design	46	21	30	3
Non-ideal reactors	23	44	32	1
Kinetics of catalytic systems	41	43	15	1
Diffusion and reaction in heterogeneous systems	40	35	21	4
Catalytic reactor design	43	39	18	-
Industrial oriented examples	32	40	26	2

TABLE 2
Undergraduate and Graduate Textbook Distribution

Textbook Author (ref)	Main Text		Reference Text	
	Undergrad	Grad	Undergrad	Grad
1. Smith, J.M.[7]	7.2	4.8	8.4	1.2
2. Levelspiel, O.[8]	25.3	8.4	27.7	7.2
3. Fogler, S.H.[9]	41.0	13.3	18.1	12
4. Hill, Sr., C.G.[10]	8.4	3	6	8
5. Froment, G.F./Bischoff, K.B.[11]	4.8	33.7	16.9	28.9
6. Carberry, J.J.[12]	0.5	5	8	8
7. Wallas, S.M.[13]	-	-	3.0	3
8. Holland, C.D./ Anthony, R.G.[14]	1.3	1.5	3.5	4
9. Cooper, A.R./Jeffrey, G.V.[15]	-	-	1	3
10. Denbigh, K.G./Turner, J.C.R.[16]	-	1.5	8	6
11. Nauman, E.B.[17]	1.5	1.5	2	6
Own Text	10.0	27.3	5.4	12.7

- Of increasing importance would be computer applications and software packages, with the introduction of more computer-assisted problem solving and experimentation as well as modeling real reactor operations.
- More emphasis should be given to non-ideal reactors and to heterogeneous reactor design.
- Some aspects of heterogeneous catalysis should be covered in depth.
- Newer applications and technologies such as biochemical engineering, pollution control, and electrochemical reactors, should be introduced.
- More industrial examples with realistic data should be used.

SUMMARY AND RECOMMENDATIONS

In a field that covers such a large mix of possibilities, it would be presumptuous to list areas for continued or future attention. Even so, there are certain areas that have the potential for significant impact on the current and future chemical industry: catalysis and catalytic reaction engineering, solid state reaction engineering, mineral processing, etc.

ACKNOWLEDGMENT

The authors acknowledge the financial support of the King Fahd University of Petroleum & Minerals for the performance of this study.

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