ChE curriculum

TRENDS IN BIOMEDICAL EDUCATION

NICHOLAS A. PEPPAS AND
RICHARD G. MALLINSON
Purdue University
West Lafayette, IN 47907

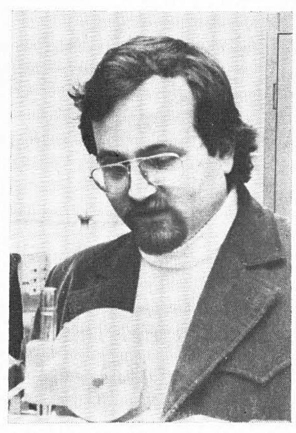
RESULTS OF A RECENTLY conducted survey on Teaching of Biomedical Engineering in Chemical Engineering Departments show that 28 schools out of 79 replying to this questionnaire offer at least one biomedical course for a total of 52 surveyed courses. Most of the courses reported are general in nature although specialized courses in biomedical fluid mechanics, biomedical mass transport, biomaterials and other areas are also taught. Five textbooks and instructors' personal notes cover instructional needs. There does not seem to be any shortage of teaching and research professors in biomedical engineering and the average class size is typical of most elective courses in chemical engineering.

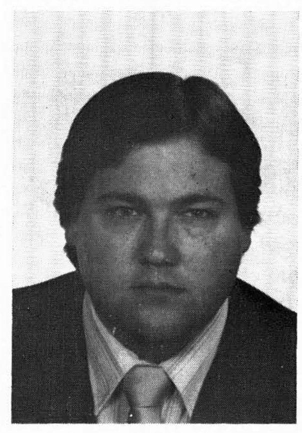
INTRODUCTION

Biomedical engineering can be defined as the application of the principles and practices of engineering to the solution of problems in medical research and health sciences. It was only very recently that this research field was accepted as a viable area of chemical engineering [1, 2], although there are indications of related research activities in the late 50's. In terms of biomedical education in chemical engineering, we have been able to identify a relevant course at M.I.T. as the earliest course of its type offered in a chemical engineering department. It was introduced in the curriculum by Professor Edward W. Merrill during the 1962-63 academic year under the title "Chemical Engineering in Biology and Medicine" and it has been offered regularly since then [3].

Biomedical engineering is considered by many as a "natural" for chemical engineers, since they are qualified to handle problems related to kinetics, fluid mechanics, mass and heat transfer in biological systems and artificial organs, as well as problems related to synthetic materials used in biomedicine. There are strong indications that with the further expansion of major companies in the area of artificial organs, qualified engineers with basic background in the area will be needed.

Those who do not feel that biomedical courses are necessary in chemical engineering point out that there is a very small market for industrial jobs in this area and that even the (rather limited number of) biomedical engineering departments and programs available in certain universities encounter problems in placing their graduates in related jobs. It has also been noted that biomedical engineering is almost exclusively a graduate subject area and that the ratio of research to other industrial positions is rather high. For these reasons, introduction of even one biomedical course in the chemical engineering curriculum is a rather prohibitive "luxury", especially in view of (i) the present popularity of other interdisciplinary areas such as energy, polymers, bio-





Nicholas A. Peppas is Professor of Chemical Engineering at Purdue University. His research interests include macromolecular networks, diffusion in polymers, biointerfacial phenomena and biomaterials. He has coauthored over fifty publications in these areas and he is director of the materials Division of AIChE and the Medical Plastics Division of SPE. **(L)**

Richard G. Mallinson obtained B.S. degrees in chemical and biomedical engineering from Tulane University (1977) and his M.S. in chemical engineering from Purdue University (1979). He is presently a doctoral candidate at Purdue. **(R)**

chemical and environmental engineering; (ii) the alarming increase of undergraduate enrollment, and (iii) the considerable teaching load of the faculty, which has not increased proportionally to the enrollments. Finally, unlike other interdisciplinary areas [4], biomedical engineering suffers from an identity problem. The average engineer confuses this area with biochemical engineering. There is confusion, even within the area, due to the development of more medically rather than engineering oriented areas such as clinical and hospital engineering [5].

A recently published British survey/report by White [6] analyzes the research background of some seventy U.S. and Canadian chemical engineers in academic institutions, who are actively involved in biomedical research. Although this report is far from complete, White estimates that there are about 400 chemical engineers involved in medical research in the USA and Canada, excluding those employed by government agencies in peripheral areas such as environmental medicine, etc. Areas of research emphasis include blood rheology and blood coagulation, heat and mass transfer in biological systems, pharmacokinetics, artificial internal and extracorporeal organs, biomaterials, adsorption and separation from biological media, and cardiovascular and respiratory research.

White points out that in the United Kingdom there are no more than 20 academic and a few industrial chemical engineers with biomedical interests. A recent study by the Fédération Européene d' Associations Nationales d' Ingenieures (FEANI) [7] does *not* include biomedical engineering as a recommended course in European chemical engineering curricula. In West Germany, the widely accepted "Erlangen alternative" does not include any such courses either in the "Technische Chemie" or in the "Verfahrenstechnik" program [7]. Therefore, it seems that chemical engineering involvement in biomedical research is an "American phenomenon"! It is exercised predominantly in academic research [6, 7] and its impact in chemical engineering is not yet known [9].

BIOMEDICAL ENGINEERING IN CHEMICAL ENGINEERING

Under the sponsorship of the AIChE Educational Projects Committee, a survey was carried out during April 1980 in an effort to analyze the trends of biomedical education, both graduate and undergraduate, within chemical engineering departments. Questionnaires were mailed to 148 departments reported in the AIChE publication "Chemical Engineering Faculties" [10], 135 in the U.S.A. and 13 in Canada. The questionnaires were sent to faculty members previously identified as having research interests in the area of biomedical engineering (about one fourth of the recipients) or to the heads of the departments when such information was not available. A total of 79 responses were received (53.4%) with 74 replies coming from U.S. schools (55.2%) and five from Canadian schools (38.5%).

The main goal of this survey was to obtain and analyze data which would show the trends of biomedical education within chemical engineering. Three types of data were used . . . type and level of course, subjects taught, and textbooks.

Several schools designated that due to the interdisciplinary nature of biomedical engineering, relevant courses are usually taught in other departments. Other respondents noted that in addition to courses offered in chemical engineering, there is a variety of courses in other departments. In processing the questionnaires we had to eliminate a few courses in biochemical engineering, since the coverage of biomedical subjects was not a major part of these courses (less than 30% of the material covered).

Twenty-eight schools offer at least one course in biomedical engineering. It must be noted, that some of these courses are offered at irregular intervals, when there is enough student interest (graduate level), and that, sometimes, a course outline may drastically change depending on the instructor teaching the course. This number corresponds to 35.4% of the responses received or 18.9% of all schools where the questionnaire was mailed. Of those that responded negatively (51), four indicated that they teach some biomedical engineering, six indicated that relevant courses were taught in other departments only and four said that they had discontinued previously offered courses. In addition, five schools stated that they had active research in this area, although no relevant courses.

The survey shows that a total of 40 chemical engineering faculty members are involved in biomedical teaching and 64 are involved in research, for an average of 1.4 and 2.3 faculty members per department respectively. These figures do not include several schools known for their strong bio-

TABLE I
Biomedical Courses Offered in ChE Departments

# COURSES OFFERED	# ChE DEPTS.	%	TOTAL # COURSES	CUMULATIVE %
0	51	64.5	0	
1	13	16.4	13 } 31	
2	9	11.4	18	59.6
3	4	5.1	12 } 21	
4	1*	1.3	4	
5	1*	1.3	5	40.4
Total	79	100.0	52	100.0

* These schools offer laboratory experiments in some or all of their courses.

medical program, either because no response was received or because this program is administered by another department (e.g. University of Utah, Case Western Reserve University). For a more accurate picture of biomedical education within chemical engineering we were able to identify through research publications, etc. [11], at least 14 more schools with active biomedical programs which did *not* reply to this questionnaire. Therefore, it can be said with some confidence that at least 42 chemical engineering schools are active in biomedical education and research.

ANALYSIS OF BIOMEDICAL COURSES

The previous analysis is hardly encouraging for the future of biomedical education in chemical engineering departments. As noted earlier, biomedical engineering may be a "luxury" in these days of high enrollments and high faculty teaching loads. To investigate this notion we determined the total numbers of faculty members for the 28 schools that offer a total of 52 biomedical courses. Only six schools from this group have less than ten faculty members, and the average size of a school offering at least one biomedical course is 14 faculty members. The majority of the schools offer one or two courses (Table I). Only six schools (21%) offer 40% of the courses.

Table II shows the number of courses at each educational level. There are 27 predominantly undergraduate (52%) and 25 predominantly graduate courses (48%). Rarities in this list include a freshman general biomedical course (at Washington University) and a sophomore course on mechanics of animal motion (at John Hopkins). All the courses meet at least two hours per week. The only exception is a general biomedical course at Purdue University which carries one credit hour.

A more detailed analysis of the subjects covered in various courses is offered in Tables III and IV. Table III classifies the various courses by area of emphasis according to the course title. There are 29 general biomedical courses (56%). Fluid mechanics and mass transport are major areas of specialized courses. A number of biomedical courses with considerable emphasis on mass transport, but also with additional coverage of other areas were judged by these authors as "general" courses. The area of systems physiology includes courses with significant emphasis on biomedical control. Three courses in biomaterials (at Rice University, C.U.N.Y. and Univ. of Washington) offer the rare case of crossection between two interdisciplinary areas, i.e. biomedical and polymer engineering.

Table IV presents information on subjects covered in the various biomedical courses as provided by the instructors for a total of 46 out of 52 surveyed courses. The cardiovascular and pulmonary systems, blood rheology, membrane transport, pharmacokinetics and artificial organs are the most "popular" subjects taught.

TABLE II
Educational Level of Biomedical Courses

LEVEL	# OF COURSES	AVERAGE # OF STUDENTS
F	1	25
So	1	12
J	6	19
J/S	3	20
S	11	19
S/G	10	10
G	15	9
All levels	5	30
TOTAL	52	16

Class size and student participation are kept at a reasonable level, typical of most elective chemical engineering courses. The average class had 16 students. The average graduate class had 10 students. The largest classes reported were at Northwestern University for a physiology course (60 students) and at Michigan State University for a general course (40 students).

Chemical engineering faculties include qualified researchers who can teach biomedical

TABLE III
Area of Emphasis and Level of Course

AREA	EDUCATIONAL LEVEL F	So	J	J/S	S	S/G	G	ALL LEVELS	TOTAL
General	1	—	3	2	6	8	7	2	29
Fluid Mechanics	—	—	—	1	—	—	6	1	8
Mass Transport	—	—	—	—	1	1	1	1	4
Systems Physiology	—	—	1	—	1	1	—	—	3
Biomaterials	—	—	—	—	2	—	1	—	3
Physiology	—	—	1	—	—	—	—	1	2
Artificial Organs	—	—	—	—	1	—	—	—	1
Animal Motion	—	1	—	—	—	—	—	—	1
Health Care Technology	—	—	1	—	—	—	—	—	1
TOTAL	1	1	6	3	11	10	15	5	52

courses. Schools reporting the highest number of biomedical researchers were University of Washington (6), Carnegie-Mellon University (5), University of Minnesota (5) and C.U.N.Y. (5).

ANALYSIS OF TEXTBOOK PREFERENCE

Additional information about trends in biomedical education is provided through textbook preference by instructors of the various biomedical courses. A total of 5 books are used as required textbooks in more than one course, while 13 books were mentioned once in this survey (Tables V and VI).

Textbook preferences have been classified in Table V according to the educational level of the course where they were used. These 68 preferences do not represent an equal number of courses, since in certain cases two books (or books *and* notes) were required for a specific course. Perhaps the most significant conclusion drawn from this Table is that the "most cited" textbook was the instructors' "notes".

Cooney's, Lightfoot's and Middleman's textbooks capture 54% of this rather small market. Cooney's textbook is used equally in undergraduate and graduate courses. Middleman's and Lightfoot's books are used predominantly in graduate courses. The only other textbooks with more than one preference were Seagrave's text and Guyton's treatise of medical physiology. Actually Guyton's text is the only one of the five written by a non-ChE. All texts are relatively new, having been published in the seventies. Reference books are rarely used. There is, however, a preference towards supplementary handouts such as review papers etc.

TABLE IV
Areas of Emphasis of 46 Biomedical Courses

AREA	EDUCATIONAL LEVEL F, So, J, J/S, S, all	S/G, G	# OF COURSES
Circulation	16	17	33
Blood Rheology	9	15	24
Membrane Transport	10	13	23
Artificial Kidney	11	11	22
Pulmonary System	10	10	20
Pharmacokinetics	7	13	20
Heart & Lung	8	9	17
Anatomy	8	8	16
Other Artificial Organs	8	7	15
Body Composition	10	4	14
Thermal Effects	4	9	13
Biomedical Polymers	5	6	11
Instrumentation	3	5	8
Physiology	2	2	4
Microcirculation	1	2	3
Others (one or two preferences)	9	10	19

TABLE V
Textbook Preference for 50 Surveyed Biomedical Courses

TEXTBOOK/AUTHOR	EDUCATIONAL LEVEL Undergraduate	S/G, G	TOTAL	PERCENT	
Biomed. Eng. Texts					
Cooney	5	4	9	21.4	
Lightfoot	—	8	8	19.0	
Middleman	2	4	6	14.3	
Seagrave	1	1	2	4.8	
Others (one preference)	3	7	10	23.8	
Other texts					
Guyton	3	1	4	9.6	
Others (one preference)	2	1	3	7.1	
TOTAL	16	26	42	100.0	61.8
Notes	5	15	20		29.4
Literature Handouts	3	3	6		8.8
GRAND TOTAL	24	44	68		100.0

DISCUSSION AND CONCLUSIONS

The main goal of this survey was to obtain and analyze data which would show the trends of biomedical education within chemical engineering. Three types of data were used for this analysis: type and level of course, subjects taught, and textbooks.

The number of chemical engineering departments that offer courses in biomedical engineering is rather small. This subject seems to be of "second priority" in most schools, and it is usually taught as an elective, where there are qualified researchers to teach it. Only two schools of those surveyed offer a biomedical course without having anyone doing research in the area. Although there are several courses for undergraduates only, most of the courses seem to be open to graduate students as well. The authors tend to believe (at least based on the comments in the responses and on the textbooks used) that most of the surveyed courses are of intermediate to advanced level. Courses which are open to juniors must be (by necessity) mostly descriptive in nature, simply because very little mathematical analysis of biological phenomena can be covered if the student has not finished at least one course in transfer/transport phenomena. As far as we know, in most schools, this is done in the junior year.

Based on the analysis of the data of this survey we believe that biomedical engineering has been "accepted" by chemical engineers to the extent that industrial needs warrant it, since the market in this area is rather small. Biomedical engineering may not really be a "luxury", but it is worth noting that most of the schools that offer biomedical courses had rather large faculties. We also believe that this field is research-oriented and it flourishes mostly through work at the graduate level. This does not mean that there are no applications for the subjects taught or researched. However, the market is limited, the competition (from various disciplines) is high, and the results and conclusions of biomedical research are "applicable" mostly to clinical cases (diseases etc.)

TABLE VI
Textbooks Cited for Use in Biomedical Courses (More than One Preference)

AUTHOR	AFFILIATION	TITLE/PUBLISHER
D. O. Cooney	Clarkson College	Biomedical Engineering Principles Dekker, 1976
E. N. Lightfoot	U. Wisconsin	Transport Phenomena and Living Systems Wiley, 1974
S. Middleman	U. Massachusetts	Transport Phenomena in the Cardiovascular System Wiley, 1972
R. C. Seagrave	Iowa S. U.	Biomedical Applications of Heat and Mass Transfer Iowa S.U. Press, 1971
A. C. Guyton	U. Mississippi	Textbook of Medical Physiology Saunders, 1976 (5th ed.)

rather than products. Significant misconceptions concerning the goals of biomedical engineering will have to be addressed by scientific societies.

Most of the biomedical courses offered in chemical engineering are of general nature. They usually include some anatomy and physiology, principles and phenomena related to the cardiovascular and pulmonary systems, pharmacokinetics and artificial organs. Specialized biomedical courses in fluid mechanics, mass transfer and control seem to enjoy some popularity, especially when they address problems related to microcirculation, diffusion in membranes and systems dynamics.

Selection of an appropriate textbook is a rather difficult task. This is not because of the lack of good texts. Actually, in our opinion, all four cited biomedical textbooks are outstanding in their own way. However, biomedical engineering is an area characterized by high individuality in instruction. Since many graduate courses are tailored to the needs of graduate research assistants working in biomedical engineering, emphasis must be placed on one or two specific areas. For example, instructors provided suggestions on additional material that could be covered in a new edition of the present textbooks. These suggestions included: design of artificial organs, thermal physiology applications, more controlled release, more biomaterials, more physiology, more quantitative texts, more and better pharmacokinetics and more thermodynamics.

This simple listing also provides an indication of present and future trends and needs of biomedical education in chemical engineering. It continues to be a predominantly graduate subject. More emphasis is given to quantitative and basic aspects and there is a definite departure from empiricism. "New" areas in biomedical instruction (not necessarily "new" to instructors, but definitely "new" for the textbooks) will have to be added, such as pharmaceutical engineering including controlled release systems, fundamentals of biomaterials, natural membrane science, microcirculation, engineering aspects of cancer research etc.

Class sizes are rather on the low side and some courses are occasionally cancelled due to lack of enough student interest. In recent years, biochemical engineering has entered a flourishing period, mainly due to excellent job opportunities and the development of industrial processes in waste treatment, biomass conversion, other fermentations, food production, etc. However, biomedical engineering is not destined to have a similar role, at least not in the next few years, unless there is a major research and industrial effort towards health problems.

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APPENDIX

The following is the list of Departments of Chemical Engineering that offer Biomedical Engineering courses and responded to the survey. In parentheses we have designated the researchers who replied. Univ. of Arizona (J. F. Gross), Carnegie-Mellon Univ. (R. K. Jain), Clarkson College (D. O. Cooney), Georgia Tech (A. Yoganathan), Johns Hopkins (S. Corrsin), Univ. of Kansas (K. Himmelstein), Kansas State Univ. (W. P. Walawender), McMaster Univ. (I. A. Feuerstein), Michigan State Univ. (D. K. Anderson), Univ. of Minnesota (K. H. Keller), M.I.T. (C. K. Colton), C.U.N.Y. (H. Weinstein), SUNY Buffalo (P. Stroeve), North Carolina State Univ. (F. M. Richardson), Northwestern Univ. (T. Goldstick), Univ. of Pennsylvania (D. Lauffenberger), Pennsylvania State Univ. (J. Ultman), Univ. Pittsburgh (J. T. Cobb, Jr.), Purdue Univ. (N. A. Peppas), Rice Univ. (L. V. McIntire), Stanford Univ. (C. Robertson), Univ. of Tennessee (W. W. Hsu), Univ. of Texas (R. Popovich), Univ. of Toronto (M. V. Sefton), Tufts Univ. (J. H. Meldon), Washington Univ. (R. E. Sparks), Univ. of Washington (A. S. Hoffman), W. Virginia Univ. (E. V. Cilento), Univ. of Wisconsin (E. N. Lightfoot), and Yale Univ. (C. Horvath).

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or related, programs to form a coherent complementary, or minor, area. All students must spend one summer in industry in a regular job after their junior year, and they must also comply with the Social Service requirement mentioned previously. However, in contrast with other programs, there is no thesis requirement for graduation.

At this point, we should mention that similar programs have been proposed at UNAM, but are still pending approval for their implementation [8]. Also, private insittutions (such as UIA) are already operating with a curriculum whose basic philosophy coincides with ours, but with differences in the form of implementations. This is due to the fact that their faculty is fundamentally part-time, whereas at UAM-I most of the faculty is on a full time basis. This brings up the point that, in order for any program to be successful, the level of preparation of the faculty members should be the highest possible, and the composition must be shifted from primarily part-time to mostly full time teachers. It is in this respect that the graduate programs in Mexico have become increasingly important, and therefore should be strengthened.

CONCLUSION

A brief review of the development of chemical industry and of the chemical engineering profession in Mexico shows that they have been in phase in terms of supplying the quantity of engineers required by industry. However, quality has been a problem, particularly in the last five years.

Mexican industry now requires a different type of chemical engineer; one capable of assimilating the imported technologies and developing new processes more suitable for the efficient utilization of our resources.

We propose the formation of an "Academic Commission" on a national level, formed by highly qualified professors from all parts of the country, in order to coordinate the design of a curriculum which could be implemented at all government sponsored schools. This curriculum should contain a fundamental core of basic science with a strong interaction with practice through lab sessions. The second stage of the curriculum must emphasize the fundamentals of chemical engineering and, finally, the third stage can be flexible and concentrate on several aspects, depending on the region of the country or the strength of the faculty at hand.

It is obvious that the implementation of the proposed curriculum requires highly trained teachers and researchers. These people should be prepared through the graduate programs now existing in Mexico. Such programs must be strengthened and should be strongly supported at the main government sponsored institutions. An overview of graduate education in Mexico will be published in a later issue of *Chemical Engineering Education.* □

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