SPACE RESEARCH COORDINATION CENTER

TWO SURVEYS OF THE NEEDS OF ENGINEERING SCHOOLS IN THE FIELD OF BIOMECHANICAL AND HUMAN FACTORS ENGINEERING EDUCATION

BY

ERWIN R. TICHAUER
PROFESSOR AND DIRECTOR, DIVISION OF BIOMECHANICS
INSTITUTE OF REHABILITATION MEDICINE AND
THE CENTER FOR SAFETY
NEW YORK UNIVERSITY

AND

ALAN A. GLASER
ASSISTANT PROFESSOR
MECHANICAL ENGINEERING DEPARTMENT
UNIVERSITY OF PITTSBURGH

SRCC REPORT NO. 124

UNIVERSITY OF PITTSBURGH
PITTSBURGH, PENNSYLVANIA

NGL-39-011-002

14 APRIL 1970

The Space Research Coordination Center, established in May, 1963, has the following functions: (1) it administers predoctoral and postdoctoral fellowships in space-related science and engineering programs; (2) it makes available, on application and after review, allocations to assist new faculty members in the Division of the Natural Sciences and the School of Engineering to initiate research programs or to permit established faculty members to do preliminary; work on research ideas of a novel character; (3) in the Division of the Natural Sciences it makes an annual allocation of funds to the interdisciplinary Laboratory for Atmospheric and Space Sciences; (4) in the School of Engineering it makes a similar allocation of funds to the Department of Metallurgical and Materials Engineering and to the program in Engineering Systems Management of the Department of Industrial Engineering; and (5) in concert with the University's Knowledge Availability Systems Center, it seeks to assist in the orderly transfer of new space-generated knowledge in industrial application. The Center also issues periodic reports of space-oriented research and a comprehensive annual report.

The Center is supported by an Institutional Grant (~~NsG-416~~) from the National Aeronautics and Space Administration, strongly supplemented by grants from the A. W. Mellon Educational and Charitable Trust, the Maurice Falk Medical Fund, the Richard King Mellon Foundation and the Sarah Mellon Scaife Foundation. Much of the work described in SRCC reports is financed by other grants, made to individual faculty members.

TWO SURVEYS OF THE NEEDS OF ENGINEERING SCHOOLS IN THE FIELD OF BIOMECHANICAL AND HUMAN FACTORS ENGINEERING EDUCATION

ERWIN R. TICHAUER
PROFESSOR AND DIRECTOR, DIVISION OF BIOMECHANICS
INSTITUTE OF REHABILITATION MEDICINE AND THE CENTER FOR SAFETY
NEW YORK UNIVERSITY

ALAN A. GLASER
ASSISTANT PROFESSOR, MECHANICAL ENGINEERING DEPARTMENT
UNIVERSITY OF PITTSBURGH

JUNE 1968

PREFACE

The two surveys of the Needs of Engineering Schools in the Field of Biomechanical and Human Factors Engineering Education were conducted for the Biomechanical and Human Factors Division of the American Society of Mechanical Engineers during 1966 and 1967 by Erwin R. Tichauer, Executive Committee, Biomechanical and Human Factors Division, American Society of Mechanical Engineers and by Alan A. Glaser, Education Committee, Biomechanical and Human Factors Division, American Society of Mechanical Engineers.

TABLE OF CONTENTS

TWO SURVEYS OF THE NEEDS OF ENGINEERING SCHOOLS IN THE FIELD OF BIOMECHANICAL AND HUMAN FACTORS ENGINEERING EDUCATION

OBJECTIVE

Several excellent surveys about the state of the art of bioengineering, biomechanics, and biomechanical and human factors engineering at American universities and colleges do already exist.[1-13]* Likewise, already under way are studies designed to determine the best syllabus structure for the training of engineers in those branches of the profession which are life-sciences orientated.[14-16] This report endeavors to complement and supplement the aforementioned two strands of inquiries with the opinion of engineering educators about the needs to train, in sufficient numbers, badly-needed professionals for the practice of our fast-developing discipline. While the purpose of the Two Surveys was to obtain information on biomechanical and human factors engineering education in particular, the results are of interest and apply to most areas of biotechnology.

* Numbers in parentheses refer to the bibliography.

THE SAMPLE

One hundred seventy-six engineering schools[17] enjoying full professional accreditation were canvassed by two different surveys.

The first survey, completed in 1966, indicated the need for additional information, so a second survey was conducted in 1967. Responses were good for both surveys, with 161 respondents for the first and 111 for the second. Both surveys were directed at the needs basic to the training of engineers, life-science orientated in their professional outlook, expected to practice as specialist engineers in their own right and not merely as, for example, instrumentation engineers, supporting programs of other disciplines. Instructions for the questionnaires emphasized that the term "course" should be deemed to include each and every scheduled activity (e.g. formal classes, laboratories, seminars, organized work by graduate students on a thesis or dissertation for a degree, supervised undergraduate projects with substantial instructional content, etc.). It was emphasized that the existence or absence of a formal curriculum in the field at the institution canvassed was not a criterion for participation and that the survey would not be concerned with questions as to whether these activities would be concentrated in one department, be interdisciplinary, multidisciplinary, be administered by individual, committee, or faculty, or even a committee of representatives from various faculties.

APPROACH

Preliminary conversations with a number of academic and administrative officers of various institutions provided convincing arguments that the surveys under consideration be best conducted at the level of interests of academic deans. The one argument, advanced most frequently, stated that most deans were well informed not only about happenings within their own faculty, but, due to service on committees and frequent formal and informal contact with officers of administration at a higher level and their own colleagues (i.e. other deans) in other faculties, they had normally a good overview about most programs, current as well as planned, throughout the entire institution. Furthermore, there seemed to be some consensus of opinion that an academic dean, even if he himself were not interested, would be in a good position to know who would be interested and forward the questionnaire to that interested and competent party to be filled in. During conversations with many academic officers, it was also concluded that a very simple, one or two-page questionnaire would well be the most likely to insure speedy, and comprehensive replies. This format was used for both surveys.

NATURE AND PROCESSING OF THE DATA RECEIVED

For the 1966 Survey, the questionnaires were divided into two groups: those returned by schools which maintained bioengineering, biomechanics, biomechanical or human factors courses, and those returned by institutions which were not active as yet in the field.

The former returned 28 questionnaires; the latter, 133, which indicates that by 1966 roughly 1 in 6 schools had organized activities of some sort in the field. Careful perusal of the raw data received lead to the conclusion that the results of the survey could best be discussed by a relatively unsophisticated, nonmathematical, and qualitative treatment of the raw data on the basis of percentage response tabulation.

For the 1967 Survey, the situation changed considerably. Institutions having a degree program or at least formal course work in bioengineering/human factors engineering and which returned completed questionnaires now numbered 58. Out of these 58 institutions, 30 reported themselves as having formal course work or programs, and the remaining 28 institutions are known to have such activities from the results of other surveys.[1,2,7] In addition, 44 out of these 58 have funded research projects in the field.[7] Another 37 institutions returned their questionnaires filled out in detail and evidently have definite interest in the field; approximately half of these already have funded research projects in bioengineering or human factors engineering.[7]

The remaining 16 respondents indicated that they had no interest at present. Thus, the 1967 Survey shows that at least 1 in 3 institutions out of the 176 canvassed has formal organized bioengineering/human factors engineering activities of some type. This indicates a doubling of the activity shown by the previous year's Survey. Assuming the other 37 institutions which have interest continue to have it, it is possible the ratio could be increased considerably in the next few years.

Since 95 institutions out of 111 responding have at least a definite interest in bioengineering/human factors engineering, it was decided to simply report the gross percentages rather than divide the data into two groups as was done for the 1966 Survey. The 1967 Survey form allowed space for the respondent to add comments if desired, and the most pertinent and interesting of these are included in the results presented below.

CORRELATION WITH RESULTS FROM OTHER SURVEYS

The doubling of activity in bioengineering/human factors engineering, which was indicated by the 1966 and 1967 Surveys, represented such a large increase that it was decided to validate this result by a closer study of the surveys listed in the bibliography.

Institutions which did not respond to the 1967 Survey but are known[1,2,7] to have bioengineering/human factors activities number approximately 39. Thus out of the 176 institutions canvassed about (39 + 58=) 97 have organized bioengineering/human factors activities of some type and the corrected ratio of activity should probably be closer to 1 in 2 institutions being active with a definite tendency to increase even more.

The number of institutions having graduate degree programs in bioengineering/human factors engineering is approximately 35, according to the ASEE Annual Directory of Engineering College Research and Graduate Study[7] and this figure has remained static according to their 1966 and 1967 results. Considering the variability of reporting survey results, this figure compares reasonably with those presented here.

On the basis of research projects and research expenditures, the increase in interest is more definitely indicated. Again drawing from the ASEE Annual Directory,[7] the number of institutions having research projects in bioengineering/human

factors engineering was 73 for 1966 with a total research ex-expenditure of $9,102,069. For 1967, 95 institutions reported research projects with a total research expenditure of $14,025,421, and this represents a 1.5 times increase in funding from the previous year.

On the basis of research projects in the particular areas of biomechanics and bioengineering, 40 institutions reported projects in these areas totalling $2,374,991 for 1966. For 1967, 66 institutions now had bioengineering or biomechanics projects with expenditures of $4,948,155. This represents roughly a doubling of research funding from 1966 to 1967 but is due primarily to large grants (over $200,000) which were received by a few institutions. For 1966, the smaller projects in biomechanics and bioengineering averaged about $42,000 over about 38 schools, while for 1967, the smaller projects averaged about $33,000 over about 60 schools. These results correlate with those of the present Surveys by showing a large increase in interest in the field with more institutions providing starting funds (as indicated by the decrease in the average project size). The fact that many institutions are doing research with minimum funding indicates the desire to do research in this area does exist, and that students and faculty are available to start larger programs when funds become available.

From the above considerations, it appears that the 1966 and 1967 Surveys did obtain a reasonably accurate cross-section

of the interest, opinions, and potential in the field of bioengineering/human factors engineering education. Evidently a sizeable increase in activity in the field has occurred during 1966-1967. This increase in activity measured in terms of new research projects, funding, or new institutions entering the field is on the order of 1.5 to 2 times the previous 1966 level. Considering the responses from the 1967 Survey plus the evidence from other Surveys, it is probably also reasonably accurate to say that now 1 in 2 institutions, or better, have activity of some type in the area of bioengineering/human factors engineering.

RESULTS FROM THE 1966 SURVEY

A. RETURNS FROM INSTITUTIONS WITH BIOENGINEERING, BIOMECHANICS, BIOMECHANICAL, OR HUMAN FACTORS ENGINEERING COURSES.

(TOTAL RETURNS: 28)

Question 1: For the purposes of maintenance and development of existing Biomechanics, Bioengineering, and Human Factors Engineering courses we have found the availability of:

	No Response	Adequate	Inadequate	Very Inadequate
Instructors	-----	7.1%	71.4%	21.4%
Research Workers	3.6%	17.8%	71.4%	7.1%
Teaching Films	21.4%	-----	35.7%	42.8%
Specialized Textbooks	21.4%	3.6%	14.3%	60.7%

This table shows that there appears consensus among experienced institutions that the availability of instructors and research workers generally is inadequate but not, in the majority of cases, very inadequate. It should be noticed, however, that many of these institutions can supply their own demand for junior instructional and research staff from within their own student body. It is worth noting that the level of response with respect to Teaching Films and Specialized Textbooks was much lower than in the case of Instructors and Research Workers. However, among those who responded, there was substantial agreement that the need for teaching films was either inadequately or very inadequately met and that in the case of specialized textbooks, in the overwhelming majority of cases, the need for such literature was strongly felt.

Question 2: In the planning of new courses to be approved in the future in Biomechanics, Bioengineering, and Human Factors Engineering we have found the availability of:

	No Response	Adequate	Inadequate	Very Inadequate
Instructors	-----	3.6%	89.2%	7.1%
Research Workers	3.6%	14.3%	75.0%	7.1%
Teaching Films	7.1%	-----	50.0%	42.8%
Specialized Text-books	3.6%	3.6%	32.1%	60.7%

It is considered that the replies to this set of questions do not vary substantially from those given to Set 1 and have probably been conditioned by them.

Question 3: The need for specialized workshop-seminars to train instructors in the Biomechanics, Bioengineering, and Human Factors field

does not exist.	-----
may exist at some institutions.	25.0%
exists at many institutions.	60.7%
is general and urgent.	14.3%

There seems to be a three-to-one consensus of opinion among experienced institutions that there exists a real need for instructor training.

Question 4: The level of training of Biomechanics, Bioengineering, and Human Factors engineers in Human Anatomy and Physiology as distinct from Psychology is at present

adequate.	
inadequate.	25.0%
very inadequate.	75.0%

It should be noted that all institutions with courses did reply to this set of questions, and there appears to be substantial agreement that it is necessary for engineers to adopt an engineering approach to life sciences and to learn to explain behavior and function of the live organism on the basis of its structure and Newtonian mechanics. Hence, the need for the development of a specialized engineering anatomy and physiology is very real indeed.

Questions 5 and 6 did not apply to this group of returns, and no answers to them were received.

B. RETURNS FROM INSTITUTIONS WITHOUT INSTRUCTIONAL ACTIVITY IN THE FIELD OF BIOENGINEERING, BIOMECHANICS, BIOMECHANICAL, OR HUMAN FACTORS ENGINEERING

(TOTAL RETURNS: 133)

It was this group which returned most of the incomplete questionnaires, and it may perhaps be concluded that these institutions replied only to those questions falling within their scope of either experience or direct interest.

Question 2: In the planning of new courses to be approved in the future in Biomechanics, Bioengineering, and Human Factors Engineering we have found the availability of:

	No Response	Adequate	Inadequate	Very Inadequate
Instructors	63.9%	-----	13.5%	22.5%
Research Workers	70.6%	26.3%	-----	3.0%
Teaching Films	86.4%	-----	10.5%	3.0%
Specialized Textbooks	63.9%	-----	6.7%	29.3%

The high level of "No Response" to this question deserves attention. Likewise, it should be noted that about 90% of those responding to the question of Availability of Research Workers found these "Adequate." Personal conversations have confirmed that a good number of institutions without organized instructional programs do have individual or organized research activity in our field, often because one or more qualified researchers accidentally "drifted" onto campus or were recruited in connection with a defense- or space-orientated pro-

ject. It should also be noted that a great majority of responsive answers found the availability of Instructors and Specialized Textbooks "Very Inadequate" rather than "Inadequate" while the situation with Teaching Films was considered to be slightly better.

Question 3: The need for specialized workshop-seminars to train instructors in the Biomechanics, Bioengineering, and Human Factors field

No response.	6.7%
does not exist.	0.9%
may exist at some institutions.	55.7%
exists at many institutions.	9.7%
is general and urgent.	27.0%

Apparently, the need for specialized seminars was considered to be either slight or very great, according to preferences by a majority of respondents. Follow-up conversations revealed that the degree of feeling was not affected in any way by the desire of the institution to consider a program at a future date if instructors were available and was distributed fairly evenly between institutions interested in a program and those who were not.

Question 4: The level of training of Biomechanics, Bioengineering and Human Factors Engineers in Human Anatomy and Physiology as distinct from Psychology is at present:

No response.	31.5%
adequate.	5.2%
inadequate.	46.5%
very inadequate.	16.7%

Again, as can be expected with this group, there was a fairly high level of "No Response" to this question, perhaps because of lack of personal experience. The frequency distribution of responsive returns, however, indicates a clear consensus of opinion expressing a need for training in Human Anatomy and Physiology. Follow-up conversations revealed that the feeling of "Very Inadequate" was practically unanimous among those institutions who had operative research programs in progress. Almost all of these, at one time or other, had needed to complement or supplement behavioral data by basic structural and functional considerations (anatomy and physiology).

Question 5: We do not have organized Biomechanics, Bioengineering, and Human Factors activities as yet because:

this is not intended to form part of our program as yet.	59.4%
no interest among the student body.	4.5%
lack of instructors.	36.8%
lack of texts.	33.8%
lack of teaching films.	7.5%

The wording of the question as well as the fact that the returns amount to 142% would, at first glance, suggest that the individual sub-questions were treated by the respondents as interdependent. Careful analysis of the rough data revealed that, invariably, those who indicated "Lack of Texts" as

principal cause laboring against organized programs simultaneously marked "Lack of Instructors:, so that there are two well-defined groups giving rational cause for lack of a program. The larger of them replied: "not intended to form part of (their) program...yet;" and the second group, slightly smaller than the first, practically infers that it is the combined lack of instructors and texts which has prevented the institution of a program. It should be noted that all respondents answered this question.

Question 6: We (would, would not) consider a Biomechanics, Bioengineering and Human Factors Program if trained instructors were available:

No response	6.9%
Would	36.0%
Would not	57.1%

This question also shows a high level of response; however, the high level of "No Response" replies to Question 2 was deemed to be indicative, in many cases, of lack of interest in the availability of instructors and teaching aids. Therefore, the reliability of replies was tested by direct follow-up conversations with a representative sample. As a result of these conversations, the opinion was formed that only about 20, or slightly more than 15%, of the respondents would, indeed, without hesitation and qualification, embark on a program if instructional personnel were available; whereas, of the 76 negative replies, 30 qualified their answers in later conversations by stating that in addition to instructors they needed laboratories, hardware, and, of course, funds. Hence, the answers to Question 6 must be treated as the least-well-considered question of the entire questionnaire.

RESULTS FROM THE 1967 SURVEY
(TOTAL RETURNS: 111)

Question 1: What do you think of the idea of broadening engineering's base from the physical sciences to include some study in the biological sciences for all students?

Like the idea.	37%
Like the idea as an option for some students.	62%
Dislike the idea.	1%

Most comments were enthusiastic about this proposal, since the general concensus among respondents was that there is a great future for bioengineering. Biological courses should be included in the engineering curriculum just as the humanities and social sciences are now. The main problem will be to fit these courses into an already crowded engineering curriculum without replacing the humanities or social sciences. Evidently a major change in the usual engineering curriculum will be required to implement this. One step in this direction that was recommended is for ECPD to accept biology in their evaluation of sciences.

Question 2: What is the best method of developing young faculty equipped to offer courses in bioengineering or biomedical engineering?

By the natural process of utilizing the graduates of current programs.	51.4%
By summer courses.	25.2%
By workshops during the academic year.	5.4%
Combination of above choices.	14.4%
No opinion.	3.6%

Evidently it is the opinion of most institutions that faculty be developed from the graduates of current programs, however, the percentages were sufficient for having summer courses and workshops as alternatives. It was suggested that the workshops could be held as part of technical or educational conferences.

Question 3: Is an associated medical school, dental school, or school of veterinary medicine essential, desirable, or not required, in connection with a biomedical engineering program?

Essential	41.5%
Desirable	50.4%
Not required	8.1%

The majority of respondents emphasized the need for an association with a medical facility.

Question 4: Are the biology courses developed specifically for medical students, satisfactory for students in a biomedical engineering program or for engineering students who desire to elect such courses?

Yes	41.5%
No	42.3%
Depends	2.7%
No opinion or don't know	13.5%

There is enough of a bias in these results to say that biology courses for medical students are not always satisfactory for engineers. Reasons given for this include too much emphasis on memorization, not enough mathematical rigor, and the requirement for having many prerequisite medical courses. The solution to this recommended by many respondents is to have special courses in biology designed just for engineers. Respondents who answered yes indicated, on the other hand, that their method enables engineers to learn how medical scientists think and therefore has more of a broadening effect on the engineer's outlook. Since most bioengineers work as a team member with medical people where it is important to have cooperation, this point of view cannot be neglected.

Question 5: Are the engineering and science courses developed for an engineering program, satisfactory for medical students, physicians, dental students, and dentists who wish to acquire some background in biomedical engineering?

Yes	19.8%
No	70.3%
Depends	4.5%
No opinion or don't know	5.4%

Evidently sufficient experience is available to make the definite conclusion that engineering courses are not suitable for medically-trained people. The major reason for this is that medical/dental students do not have enough background in mathematics, physics, and basic engineering concepts. The solution suggested for this is to provide the engineering background by means of well-designed short courses. Developing such courses would be a challenge since experience shows that engineers apparently have less difficulty when taking medical courses than medical/dental students who are taking engineering courses. Evidently it is difficult to replace years of engineering training and experience by a short review of basic engineering, since medical/dental students generally have the same high school and early college background as engineering students and ought to be able to do as well given sufficient time.

Question 6: Can students who have a B.S. in engineering hope to satisfy the requirements for an M.S. or Ph.D. in biomedical engineering as rapidly as they might in more conventional fields? If not, how much more time would be required for the biomedical engineering programs?

Yes	47.8%
No	45.9%
Depends	2.7%
No opinion or don't know	3.6%

Additional time required is: 1/2 to 3 years

At a good percentage of institutions completion of graduate work in bioengineering does take longer. To insure the growth of this field, we are obligated to reduce this additional time.

Question 7: What do you think of the idea of adding functional anatomy and kinesiology to the existing instruction in physiology and psychology or as a replacement for one of the courses in the social sciences or humanities?

Like the idea	44.2%
Dislike the idea	35.1%
Depends	1.8%
No opinion	18.9%

Those opposing this idea indicated that the engineering curriculum is already crowded, and if anything, it is the physical sciences that should be replaced instead of the liberal arts courses. Such a combination course would have to be carefully planned and integrated to meet engineering requirements. Present courses in these areas are generally taught descriptively without the mathematical rigor demanded by engineers.

Question 8: Should the U.S. National Committee on Engineering in Medicine and Biology, which is already operative under the auspices of the National Academy of Engineering, act as a committee of liaison between the physical sciences and the life sciences?

Yes	67.6%
No	13.5%
No opinion	18.9%

This question provided space for the respondents answering negatively to state the reason for their position. The most notable comments included such things as:

"It is not broadly enough concerned with physical science."

"There are liaison groups in environmental engineering which can be expanded to do this."

"This work is better done locally."

"I have no faith in this group."

"Let's not get bureaucratic."

"The present committee needs some modern active bio-engineers on it."

Question 9 asked the respondent to give his own definitions of the terms biomechanical engineering, human factors engineering, and biomedical engineering. The definitions listed below are a summary of the responses received. Of the three terms, the most widely recognized was biomedical engineering.

Question 9: How do you define Biomechanical Engineering?

Responses:

"The application of mechanical engineering to problems of biology and medicine."

"We don't."

"I don't like this term."

"Never heard of it before."

"The N.I.H. is studying definitions."

"Fragmented disciplines are hard to define."

"Good luck on this!"

How do you define Human Factors Engineering?

Responses:

"The study and application of human physical factors in engineering."

"The engineering of man-machine systems."

"The study of the response of man to engineering environments."

"The application of engineering in support of psychology."

"We don't."

"I can't."

"I wish I could."

How do you define Biomedical Engineering?

Responses:

"The application of engineering to biological and medical problems."

"The instrumentation measurement and analysis of physiological systems and the design of artificial organs."

"The application of engineering in the solution of clinical problems."

"It is already defined in the scope of the IEEE Biomedical Committee."

"The definition for this includes the other two."

"There are ten different ways to define it."

"I don't!"

"I wouldn't use the word."

The interested reader is referred to Martin[2] and Sauer and Nevins[6] for more concise definitions of terms used to name the various areas of biotechnology.

Question 10: If you desire to make additional comments concerning bioengineering/human factors engineering, place them in the space below. If applicable, state your research and training objectives in bioengineering/human factors engineering.

Of the 111 respondents, 33 gave responses to Question 10, and these are summarized as follows:

"This is a rapidly growing field."

"All departments are interested."

"We are establishing a bioengineering department."

"To make a contribution in these areas, one needs to be an exceptional engineer."

"We want to train M.S. and Ph.D engineers who can serve on interdisciplinary teams."

"We need engineers in this field."

"I favor undergraduate bioengineering courses as the best means to develop good bioengineers; these graduate programs don't do a thorough enough job."

"Once you get the research, then bioengineering training programs can be developed."

"We don't consider designing equipment as bioengineering."

"Your questionnaire is loaded!"

"Your survey is most interesting; we would be interested in seeing the results."

"We are eager to hear more about this work."

"Keep up this work; it is needed."

"This is one of the frontiers of the 20th century."

The following areas of research were mentioned in the responses to question 10: sanitary engineering, environmental engineering, instrumentation, clinical problems, biomechanics, prostheses for humans and animals, safety research.

SUMMARY

The important results of both surveys can be summarized as follows:

1. The basic physical science courses taken by every under graduate engineer should include the fundamentals of biology, anatomy, and physiology.

2. In order to develop any biomedical engineering program, it is the opinion of most schools that an associated medical school, dental school, or school of veterinary medicine is essential or at least desirable.

3. For the purpose of planning, developing and maintaining courses in biomechanics, bioengineering, and human factors engineering, the availability of instructors, research workers, teaching films, and specialized textbooks is inadequate.

4. The best method of developing young faculty equipped to offer courses in bioengineering is, in the opinion of most schools, by the natural process of utilizing the graduates of current programs. Acceptable alternatives are summer courses for faculty and specialized workshop seminars which could be held as part of technical or educational conferences.

5. Biology courses developed specifically for medical students are not always satisfactory for engineers since they lack mathematical rigor and place too much emphasis on memor-

ization. Special biology courses designed for engineers are favored as a solution to this problem. On the other hand, engineering and science courses developed for an engineering program are, in the opinion of most schools, not suitable for medical and dental students who want to learn some bioengineering. The primary reason for this is that medical and dental students lack the basic mathematics, physics, and engineering principles which are regularly applied in bioengineering courses.

6. Completion of graduate work in bioengineering can take longer than in the more conventional engineering fields. For the Ph.D. in bioengineering, the student may require one-half to three years beyond that required to complete the usual PH.D. in engineering.

7. The U.S. National Committee on Engineering in Medicine and Biology should continue to act as the committee of liaison between engineering and the life sciences.

Approximately 133 institutions which responded to the Surveys have no bioengineering, biomechanics, biomechanical or human factors engineering department with a formal degree program; however, over half of these are interested in establishing programs when funds, instructors, and textbooks become available. Of the 176 institutions surveyed, it appears that at least 1 out of 2 are active in some way with graduate and faculty research, special courses, undergraduate projects, and/or faculty bioengineering committees. With 1 in 2 institutions now having activity in the area, there will undoubtedly be more efforts made to incorporate bioergineering/human factors principles into the engineering curriculum.

The impetus for the establishment of new curricula and programs comes from the many students and faculty[7,10-13] who now recognize bioengineering in its many facets as one of the frontiers of our century.

ACKNOWLEDGEMENT

We are greatly indebted to the deans of all engineering schools participating in this inquiry for their extremely speedy and prompt attention to the questionnaires. Very special thanks are due to many deans or their deputies who took great pains in expressing valuable opinions, be it as professional engineers or as educators, about the future and the needs of the bioengineering programs in this country.

BIBLIOGRAPHY

1. "Bioengineering programs in the United States," Engineering Foundation, New York, 1964.

2. Martin, Josephine, N., "Biomedical Engineering Education," Medical Electronics News, Rimbach Publications, Pittsburgh, 1966.

3. "Biomedical Instrumentation Publications," Medical Electronics News, Rimbach Publications, Volume 8, No. 2, March 1968, P. 15.

4. Aronson, Milton H. and Josephine N. Martin, "Survey of Biomedical Computer Applications," Medical Electronics News, Rimbach Publications, Pittsburgh, 1967.

5. Arthur, Robert M., "Bioengineering Survey," Journal of Engineering Education, Vol. 55, No. 10, June 1965.

6. Sauer, H. J. and Nevins, R. G., "Biotechnology and the Mechanical Engineer," Mechanical Engineering, December, 1965.

7. "Annual Directory of Engineering College Research and Graduate Study," Journal of Engineering Education, Vol. 57, No. 7, March 1967 and Vol. 58, No. 6, February 1968.

8. "Goals of Engineering Education," Final Report, Journal of Engineering Education, Vol. 58, No. 5, Jan. 1968, pp 436-438, 476.

9. Ferris, Hansford W., "Trends in Engineering College Research," Journal of Engineering Education, Vol. 58, No. 9, May 1968, pp. 1059-1062.

10. Fung, Yuan-Cheng B., "Biomechanics, Its Scope, History, and Some Problems of Continuum Mechanics in Physiology," Applied Mechanics Reviews, Vol. 21, No. 1, January 1968.

BIBLIOGRAPHY

11. Von Gierke, H.E., "Biodynamic Response of the Human Body," Applied Mechanics Reviews, Vol. 17, No. 12, December 1964.

12. Merrill, E. W. and R. E. Wells, Jr., "Flow Properties of Biological Fluids," Applied Mechanics Reviews, Vol. 14, No. 9, September 1961.

13. Contini, R. and R. Drillis, "Biomechanics," Applied Mechanics Reviews, Vol. 7, No. 2, February 1954.

14. Salkovitz, E. I., "Symposium on Dimensions of Biomedical Engineering," University of Pittsburgh, 1967.

15. Latham, Allen, "Scope of Research Interest of the Biomechanical and Human Factors Division," ASME, Biomechanical and Human Factors Division Newsletter, April 1968, April 1969.

16. "Report of the Commission on Engineering Education," "New Directions in Laboratory Instruction for Engineering Students," Journal of Engineering Education, Vol. 58, No. 3, November 1967.

17. "Membership Directory of ASEE," Journal of Engineering Education, December, 1965 and 1966.