AN INTRODUCTORY STUDY TO ASSIST IN THE DESIGN OF CURRICULA FOR THE SUBJECT AREA OF BIOENGINEERING

by

Velio A. Marsocci
Professor of Engineering and Chairman
Department of Electrical Sciences

CEAS #237

College of Engineering
State University of New York at Stony Brook

May 1972

PREFACE

In the early Spring of 1971 arrangements were made by the author for his sabbatical leave; simultaneously, a desire in the College of Engineering to initiate the planing of curricula for Bioengineering programs led the author to suggest the use of a large portion of his sabbatical time for the purpose of visiting, and obtaining information concerning Bioengineering, from the hospital centers and medical teaching centers in the New York City-Long Island area. The plan was discussed with Dr. Edmund Pellegrino, Vice President of the Health Science Center and Professor Daniel Dicker, then Executive Officer of the College of Engineering. It was decided that such an activity would, in fact, be valuable in helping to formulate plans for the design of the aforementioned curricula. Dr. Pellegrino provided the names of hospital directors of the large medical centers who could be contacted for the purpose of initiating discussions. The sabbatical leave was subsequently approved by the Academic Officers and the President of the State University at Stony Brook. At each and every one of the institutions visited the author was given the utmost of cooperation and of time by personnel in both the administrative offices and the medical departments associated with those institutions. The total list of names of the people who contributed to the project and who have the appreciation and gratitude of the author is far to lengthly to be mentioned in the present document. It should be mentioned that the information and the opinions contained within the present report do not necessarily reflect the opinions of the personnel in the medical centers, with whom the author interacted, but are the interpretations, by the author, of those conversations and of the activities observed in the hospitals.

The author also agreed, at the outset, to provide a report, regarding the visits to the medical centers, to the Office of the Vice President of

Health Sciences and the to the Office of the Dean of Engineering. The present document is respectfully submitted as constituting that report.

State University of New York at Stony Brook

May 1972

INTRODUCTION

The manner in which new curricula are usually developed at most academic institutions proceeds from a decision by academic personnel regarding the objectives of a new subject area and to develop courses, with the attendant course descriptions which will service such an objective. The courses, after being presented for a number of subsequent years, are adjusted in scope as feedback, via the experiences of the graduating students, becomes available. These experiences provide information as to what modifications in the courses are required in order to have the course material more nearly coincide with the career situations which the students encounter over a period of years. Hopefully the course content that eventually ensues will generate graduates with a more appropriate academic experience. However, this approach requires a relatively lengthy period of time during which the trials and errors of course development begin to reduce the error between the kinds of material given in a particular course and material actually useful to the students. During the 1971-72 Academic Year plans were initiated at the College of Engineering at the state University of New York at Stony Brook for the development of bioengineering curricula. The author of the present report was involved in these plans, and he suggested that it might be advantageous to use a large portion of his sabbatical time in order to visit the large hospital centers and medical teaching centers in the New York City-Long Island area with the purpose of obtaining information as to the orientations which the design of bioengineering curricula should take. The procedure would thus provide a format whereby the faculty involved in the curricula development would be receiving information directly from the hospitals and from the hospital personnel; these are essentially the ultimate consumers of the bioengineering graduate. This would serve to shorten the feedback loop whereby the information, as to whether a particular curriculum was successful or unsuccessful could be utilized to guide the appropriate course alterations. The essential question which was to be asked the members of the various hospital staffs is essentially the following: What do medical centers require from engineering in the way of a technological backup for the delivery of health services? Asked another way: If engineers are to be employed in medical centers or in other industrial institutions who supply equipment and services to the hospitals, then what kinds of academic subject matter and other experiences should the engineers be exposed to during their training period? Thus, with such a question the author was essentially in the position of asking the medical personnel: What is it that you need from engineering and what it is that we, in engineering, can do for you? This information would then be reported back to the appropriate academic bodies involved in the planning of curriculum and hopefully could provide a basis for the curriculum development. The hospitals which were visited included Downstate Medical Center, State University of New York; Nassau County Medical Center, East Meadow, New York; the Mount Sinai School of Medicine, NYC; The New York Hospital-Cornell Medical Center, NYC; the Long Island Jewish Medical Center, New Hyde Park, N.Y.; the Albert Einstein College of Medicine, Yeshiva Univ., Bronx, N.Y.; the NYU Medical Center, NYC; and Columbia University, College of Physicians & Surgeons, NYC. It should be mentioned at the outset that the remarks and the outlines presented in what follows do not necessarily reflect the opinions of the personnel with whom discussions were held. Rather they represent the impressions received, by the author, from these discussions and from the kinds of activity which he saw taking place in the institutions. The most vivid overall impression received during the visits was that the term "Bio-engineering" could in no way represent a single set of pedagogical subject matter which could be placed between covers of a single textbook or within the confines of a course of one or two semesters, and to which a student could be exposed so as to produce a bioengineer. The aspect of engineering in medical institutions or medically-related industries is as many faceted as is engineering in any of the high-technology endeavors such as aerospace, electronics, systems engineering, etc.

The usual procedure followed in arranging for the visits to the hospitals involved a prior call to the chief administrator officer of the hospital center with whom an appointment was made. The visit was initially made to the director, and later to other personnel on his staff. In some instances the director provided the author with an introduction to those personnel whom the author could contact directly. At every institution visited the author was given a considerable amount of cooperation and of attention and in most cases was provided with opportunities for discussions involving both the administrative personnel and the medical personnel of the institution. Later, a tour was usually tendered in which the author was brought to those parts of the hospital involving the engineering activity. These tours included visits to Intensive Care Units, Corocary Care Units, the hospital plant engineers, and, in those cases where electronic and instrumental engineers already existed on the staff, visits to their facilities. While it would be imprudent for the author to make comparisons between specific institutions it nevertheless should be mentioned that the impression received during these visits indicated that the personnel on the hospitals staffs, whose presented the technological backup of the medical activities (such as service personnel for the electronic equipment, engineering personnel on the staffs of hospital administrators, pe[illegible] aiding with hospital planning and organization, computer specialists, etc.), ranged in number from one or two in some hospitals to a staff of 30 or 35 in at least one hospital. In this latter case the personnel included approximately five engineering specialists who were engaged in a department of medical instrumentation. The latter case was, however, outstandingly unique among the institutions visited in that none of the others come close to that level of activity in the present context.

In every institution visited it was apparent, however, that the administrative personnel and medical personnel recognized the need for technological backup, especially in the use of some of the newer electronic equipment, the prosthetic equipment and in the medical research already in progress. However, the budget constraints with which hospitals are presently faced make it very difficult for medical personnel to agree to reduce budgets in those portions of the hospital activity involving direct patient care in favor of providing funds for the employment: of engineering personnel for the design and the maintenance of equipment, and for other interactions with the medical services and administration. This is, of course, understandable, and it should also be made clear that the advent of the engineer in such organizations is in its very early stages. The engineer, for the present, comes into the hospital essentially as a guest, and in order for the medical personnel to feel a need for his presence and 'for the value of engineering personnel as part of the medical team it will be necessary that the engineer earns his way in the hospital activity. That is, high productivity will be a requirement, from those engineers who initially join hospital teams, in order to provide a basis for further expansion of engineering departments within the hospital. It will be necessary for those engineers who do, in fact, join the staffs of medical institutions to maintain an attitude of innovativeness, flexibility and a willingness to search out the needs of the medical team and to provide those needs, as well as to develop and to direct engineering activities in a manner indicating to medical personnel what new things engineering talent can provide. It was also evident, in some of the institutions where there may have been some initial resistance to the presence of non-medical personnel as part of the direct patient-care activity, that once engineers made their talents felt this resistance seemed to disolve very rapidly and the medical personnel became very willing to utilize the engineering talent in the delivery of health services.

The following portions of the report discusses the aspects of engineering from the subject of hospital construction through a spectrum of activity up to and including medical research. It was, however, obvious that the very immediate needs of hospital centers, for engineering talent, focuses on'the following areas: (1) the organization of both the administrative functions and of the physical plant of hospitals, (2) the flow of information throughout the hospitals (this is not only medical information, but includes information of an administrative nature) and (3) the acquisition, maintenance and use of .the medical instrumentation.

Hospitals are presently repositories of a great deal of electronic equipment, as well as equipment which operates and is controlled by electricity. The equipment, for the most part, is purchased by the hospital on the basis of information provided by the vendor, who convinces a physician that he requires the equipment- In many cases, although this need may be valid, the equipment being brought into the hospital, according to many reports, is found not to be operating at the proper level of performance, and the specifications for such equipment are apparently not what they should be especially with regard to the safety of patients and of personnel using the equipment. A further consistent complaint, heard during the visits, concerned the flow and the retrieval of information throughout a hospital system. It was mentioned, repeatedly, that while there is a voluminous amount of data being recorded by the various equipment in the hospital and that such inforsation is being inserted into hospital records including computerized systems, it is extremely difficult for the medical personnel to retrieve that' portion of the information useful to them for their immediate purposes and in a language which they can understand. These personnel find that it is extremely difficult, for instance, to "pull the charts" on a patient by a method other than reverting to the usual one of a handwritten chart hanging on the patient's bed.

Therefore, if any conclusion that can be reached about those areas in which the engineer would find immediate opportunities, those that appear to be most evident are computer engineering, electronics, instrumentation engineering, engineering involving prosthetic devices and engineering involving the design and the organization of hospital activity.

The importance of continuously monitoring the career opportunities in the field of bio-engineering cannot be overstressed. The information will provide the necessary feedback in order that the modification of curricula and of syllabi be as rapid as possible. That is, every attempt should be made to prevent an occurence, once again whereby a large number of graduates are injected into what is apparently a highly viable professional field only to find that, by the time students have gone through the usual four of five years' of educational experience, the field has been saturated. Situations in which this has happened (i.e., physics, chemistry, mathematics, aerospace engineering, etc.) are already well-documented. The constant monitoring of career opportunities should be an essential part of the development of all future academic programs.

In the following sections there are given outlines, by categories, of the various types of engineering with which interaction is possible in medical centers. It should be emphasized that the subject of the present report describes the impressions from visits to hospital and teaching centers in a limited geographical region. The possibility for engineers to enter medically-related fields via "non-medical" institutions is certainly not to be ignored. The latter group of engineers will find employment with manufacturers of medical equipment and with institutions which supply services to the medical centers. In point of fact, it is probable that more engineers will be employed by the latter kinds of institutions than will be employed in the hospital centers themselves. Further, the order of the categories in this report is not meant to represent the order of importance of the engineering activity in the hospital. It is meant simply to provide a structure for the discussion.

It is important to emphasize that the opinions expressed by thk author in this report are based on his visits to the nine hospital centers, as mentioned, and that these opinions and impressions may or may not coincide with the data collected by governmental committees at the state or federal levels, or with the' many reports describing how engineering has been successful in supporting health-science activities. The present document describes only the author's impressions and presents recommendations, based on these impressions, to the College of Engineering and to the Health Sciences Center, and will hopefully assist in the design of a curricula for bioengineering programs.

CATEGORIES OF ENGINEERING ACTIVITY IN MEDICAL CENTERS

The list of categories which follows does not intend to describe the structure of departments but simply indicates an arrangment of engineering activities. In each of these categories there will, of course, be interaction not only by engineers from category'to category but by engineers with the nonengineering personnel in medical departments. It is probable that the engineers in categories 4, 5, 6 would be those who are generally involved with assisting the physicians with the direct patient care and those engineers in category 7 would be involved possibly with medical-science personnel (i.e., personnel with the MD and/or Phd in medically-related areas such as physiology, anatomy, etc.), and, in general, would be those engineers who would become part of a research team not necessarily involved in direct patient care. The first three categories are comprised' of engineers who are concerned with the construction, maintenance and operation of the hospital rather than having an involvement with the medical services directly. In the present section of this report the categories are merely listed for identification and the succeeding section will give the detailed descriptions of the categories. That section will also provide information regarding the discussions, of these various categories, held with the personnel in the medical centers visited. Included in the later sections of this report are recommendations by the author, based on his impressions as received from these discussions, concerning the engineering additions which should be made to the staffs already generally present in medical hospitals and/or the training of future bioengineers.

I. Construction and Design of Medical Buildings:

This activity is concerned primarily with civil engineers, structural engineers, and systems engineers; and secondarily, with electrical' engineers and mechanical engineers. The latter two types of engineers are involved with the design of electrical power distribution throughout the buildings, the generation of power, heating and air conditioning.

II. Plant Maintenance:

The category includes civil engineers involved with the rehabilitation-construction of medical buildings and the liaison. with personnel from the offices of architects and structural engineers as contracted for the design and the construction of hospitals. This activity also 'includes the electrical engineers who would be responsible for maintenance of electric-power generation and distribution facilities, as well as for modifying existing electrical installations in the hospital and in other medical buildings. Also included are mechanical engineers who give attention to such matters as the heating plant and also assisting with power generation and with air conditioning. The latter might well require services of a specialist, (i.e., an air-conditioning specialist who would be trained specifically for the special problems which air conditioning in hospitals encounter).

III. Hospital Administration:

The requirements associated with this category include industrial engineers, engineering economists, engineering planners and computer engineers. Further, the services of computer specialists such as programmers, mathematicians and other personnel trained in the use of computer equipment, will necessarily be encountered. Systems engineers will also provide a large segment of the talent needed in this activity.

IV. Instrumentation and Communication:

This category involves primarily the electronics engineers, with that group comprising instrumentation specialists and communication specialists. The latter engineers are concerned with radio, television, and the intercommunications systems within the hospital structures as well as tele-comxunications facilities frcm hospital to hospital, and from hospital to mobile units such as ambulances.

V. Prosthetics:

The group includes electrical engineers, electronic engineers, mechanical engineers and materials engineers. These personnel will interest strongly with those described in categories 4 and 6.

VI. Physiological Systems:

This category is comprised of personnel concerned with the modelling and the analysis of complex physiological systems. Personnel from the engineering part of the team will be electrical engineers, mechanical engineers, chemical engineers and, possibly, some materials engineers.

VII. General Research and Teaching:

This category involves all. phases of engineering and will vary from research team to research team. The teams will nucleate, not necessarily by the type of degree held by the personnel, but will be motivated by the proclivities of the various engineers and medical scientists; this will place these teams in any of several categories.

DETAILED DESCRIPTION OF ENGINEERING ACTIVITY IN MEDICAL CENTERS

In the following paragraphs each of the engineering categories, as described in the previous section, are discussed in detail. The impressions received by the author, concerning the kinds of engineering and the engineering training which hospital personnel have indicated as desirable from their viewpoint, are outlined. The results of the discussion are then brought forth, later in the report, with general recommendations for the design of curricula for a general category of bioengineering. In every case, during these discussions, the hospital personnel were asked to give some suggestions as to how, from their own experiences, they would recommend that engineers be trained for implementation of the various categories. The respondents were informed that the author was entirely willing to accept answers which ranged from "no changes should be implemented in the engineering programs, i.e. the present manner in which engineers are produced is sufficient for the purposes of the medical centers", to the other extreme indicating "toss our everything that is presently being for the education of engineers and invent a whole new method of engineering training specifically designed for the medically-related professions". Obviously, it was to be expected that the answers would fall somewhere between these two extremes. The actual opinions given did vary from institution to institution. However, there were certain consistencies, in the opinions, to which the author brings attention in the present report.

Once again, it is to be emphasized that the report represents a reaction to the way in which the personnel in medical centers presently envision engineers and is meant to serve as one input, along with many inputs and reports by other individuals, who have undertaken the collection of data involving engineering activity and engineering training for the medically-related fields. The categories listed below are similar to, and are in correspondence with, those listed in the previous section.

I. Construction and Design cf Medical Buildings:

The discussions which are placed into this category generally centered on interviews with the hospitals' administrative personnel, whoever, in many cases, personnel who have the medical degree and have worked initially in medical departments, but who have left these activities to assume supervisory roles in administrative offices. It was generally felt that the present schemes by which civil engineers and structural engineers are trained are certainly adequate for the purposes of the actual construction of a hospital or other medical building, but what seemed to be lacking in the academic procedure was the infusion of an understanding on the part of the personnel from the engineering ranks, as to the way in which the special organization of a hospital needed to be included in their designs for such buildings. That is, it was evident that some lack was existent in communications between the personnel in the medical centers and those in the office of the architect. The lack 'of understanding between the two was especially prevalent, for example, in describing or in coming to some conclusion as to the best way of arranging space in a hospital. There was also expressed the opinion that in many cases the office of the architect does not have, as part of their team, people sufficiently versed in certain areas of speciality to produce an efficient design. For instance, there does not seem to be a understanding on the part of some personnel in the office of the architect as to the basics of designing installations involving some of the more recently-acquired equipment such as computers and some of the electronic equipment. It was generally felt, however, that the engineers who are to be trained for this category do not actually require specialized training in medically-related fields (such as biology, organic chemistry, physiology, etc.) but, that they should receive

.. d basic training in the principles of civil and structural engineering; ·trical engineering and/or of mechanical engineering as they apply to ·tal construction, It was generally felt that perhaps an internship, ·by some personnel from the architectual engineer's office would spend ·in a hospital center interacting with hospital personnel and with the ·al procedure, is a valuable experience that would permit engineers to some understanding of the viewpoint of the medical people and of the ·ure in which health delivery services are arranged'throughout a hospital. ·thor also received a very definite impression, from the comments made ·e medical and the administrative personnel in the hospital centers, that ·eem to feel a lack of analytical ability on the part of many of the ·truction engineers whom they had encountered during interactions with the va·ous offices of the architects. It is the present author's opinion that this lack of an analytical approach in the work is somewhat characteristic of many present-day civil and structural engineers. During the past 20 years the glamour of such fields as electronics and aerospace engineering (whose subject matter was taught in terms of a highly-analytical approach) together with the large popularity of such fields as physics, chemistry and mathematics, attracted away from the civil engineering and construction engineering fields those students with proclivi-ties of an analytical nature. As a consequence, the civil and/or structural engineers who have been graduated-for. the past two or three decades probably were not engineers who felt the necessity for developing their analytical faculties. One may question whether the structural design of a hospital building requires as high a level of mathematical analysis as, say, an aircraft design; however, when one needs to include in the plan not only the analysis of stresses in the individual structual members if the building as well as he overall architectural (asthetic) design but also needs to include a high degree of efficiency for the utilization of space (which will involve statistical analysis, systems analysis, etc.) then it is evident that the lack of ability of the design personnel to perform in these subject areas is significantly felt by those who must interact with them.

II. Plant Maintenance:

Although it is generally told as an apocryphal tale it is perhaps very true, that when one asks for the engineering staff in most hospitals, the hospital staff tend to give the directions to the maintenance department in the institution. That is, the general concept of what an engineer does relates to that which is performed in the "maintenance division". It is only in the more advanced hospitals, and in the recent thinking in hospitals, that medical personnel and other non-engineering hospital personnel have begun to recognize that engineers perform in activities other than maintenance. In speaking to maintenance personnel it was found that, for the most part, these were comprised of civil engineers who are associated with therehabilitation of construction within the medical buildings; that is, where modifications to existing buildings are to be made. They also perform a liaison service with the office of the architect for the construction of new medical buildings. The plant-maintenance departments also house engineers who are responsible for the generation and the distribution of electric power. The installation and maintenance of intercommunication equipment (intercoms, radio closed-circuit TV, etc.) is usually under the jurisdiction, at present, of maintenance personnel. The same holds true in the case of the mechanical engineers who are generally concerned with providing the heating for the hospital buildings, who interact with the electrical engineers in the genration of power, and are also concerned in general, with the machinery which helps operation the institution. There is a speciality, within the purview of mechanical engineering, which is especially important to hospitals; and that has to do with air conditioning. It is an impcrtant and a rather large problem in hospitals that the air conditioning be designed in a special way. One of the consistent problems mentioned in the Ciscussions related to the fact that the air conditioning, for example, between the operating rooms neededto be designed so that the equipment not only provided temperature and hum dity control, but that the additional design specification, regarding the spread of microbiotic infection from one room to another needed to be included. Thus, the air-conditioning engineer responsible for the design and installatiox of such equipment in the hospital environment would need to have some background in the biological sciences as well as in the conventional engineering subject matter (there apparently has been very little attention given to the solution of this problem of air-conditioning for hospitals and at the present time it constitutes a serious problem, especially in the operating room wings of many of the hospitals). Here again, it was felt that there need be no extensive modification of the way in which the engineers in this category were trained, and there was a repeat of the opinion that it is perhaps best if engineers, who intended to work in hospital centers, were to receive as part of their training some internship period providing an actual experience within the hospital environment. The maintenance departments do feel a dire need for the up-dating and the up-grading of the background of their personnel. as well as for the addition of more engineering specialists (with academic degree) to the existing staff.

III Hospital Administration:

This category will, for the ~ ~part, be staffed by the industrial engineers, engineering economists and those engineering personnel involved with long and short-range planning in the sense of operations research. The serious need in present planning is associated, essentially, with the development of a long-range planning staff, That is, a staff which can attempt to make predictions, which will be valid over long periods of time, as to the medical needs of the surrounding community so that hospital planning can be performed so as to result in a system which can satisfy those requirements as well as, for example, the requirements imposed by the extreme budgetary situation which presently faces most health-delivery centers. These constraints require a more educated way of planning the financial operation of such institutions than has usually been the case; it is of great necessity that systems analysts, be added to the staffs, who have the capability of constructing adequate models which include the financial structure as well as the physical. structure (i.e. arrangements of space, etc.) of the medical center.

Although computer engineers and specialists might not seem to fit in a category entitled Hospital Administration they are being included in this category because of the manner in which many such engineers will interact with the hospital staff. By far the largest portion of the computer activities will, at least for the near future, probably have to do with hospital records (medical and financial), budgetary infornation, coordination of services, etc., which in most hospitals is generally under the aegis of the administrative offices rather than under the direct supervision of the medical departments. However, this does not preclude the fact that much of the computer activity will be directly servicing the medical departments and the work of the medical personnel. There can be no doubt that the staff of computer specialists will include more than computer engineers who will be responsible for the purchase, installation, maintenance and general operation of computer facilities. The staff of the computer facilities will obviously require the services of ~oft--warespecialists such as programmers, mathematicians and linguists. In the medical departments themselves there exist and/or will develop rapidly medical teams, who are either of themselves medical-engineering specialists or will be comprised of engineers and medical-science specialists, and who will provide the medical backup required at the input end of the computer (i.e., insure that data gathered via patlent-monitoring will be handled so that the input to the machine will be done in the most valid and the most efficient manner). It can be foreseen that, as the utilization of the instrumentation and the computation equipment becomes more common, the interaction between the engineering specialist and the medical specialist will develop so that eventually the medical specialists will themselves become adept in the operation of the equipment. This will free more engineering time for the "higher" technical tasks.

A very consistent complaint, given by many physicians, was concerned with the flow and the retrival of administrative and of medical data in the hospital systea. Medical personnel stated that although the great amounts of data concerning, for instance, a patient's medical status were being continuously generated, it was extremely difficult to retrieve, at random, a specific piece of information in a mode understandable to medical personnel making the request. This exemplies another immediate demand for engineering talent in medical centers. That is, in the area of the organization of hospital activities fron the viewpoint of data processing and information systems; this applies not only for the internal organization of the individual center but for the design of the interacting network linking the activities of many hospital units. This system also includes links with mobile units (i.e. ambulances, or nobile health care units) and, in time, with out-patients who are being observed by on-line monitoring equipment located in their own homes.

IV. Instrumentation and Communication:

The engineering personnel in this category will be, predominantly, electronic-instrumentation specialists although there will exist requirements for instrumentation specialists whose areas of expertise may be in mechanical engineering, in chemical engineering or in materials engineering. The category also includes the communications-engineering personnel concerned with the radio communication and closed-circuit TV communication within the hospital, as well as with telecommunication systems between the hospital center and mobile units such as the ambulances or between one medical institution and another. The latter may possibly involve both telecommunication and cable-communication equipment. Certainly, the intercom systems and communication systems serving as warning and signalling systems and conveying information other than medical data may also be listed in this category. However, it is most likely that the instrunentation specialist and the communication specialist (that is, the communications engineer who does not directly aid the physician in patient care) will probably function from different administrative units.

One of the most immediate technological problems faced by the medical center stems from the inability to adequately cope with the large amount of electronic instrumentation already housed in the facilities. The present-day literature is replete with accounts of how electronic equipment will soon comprise a major portion of the medical tools used by practitioners. These accounts seem to predict occurrences which are in the future vein. However, it is a fact that, in a geographical area such as the Northeastern U.S., probably every hospital including most small ones already have installed Intensive Care Units (ICU) and Coronary Care Units (CCU) as well as a multitude of other electronic equipment; some on a mobile basis which can be rushed throughout parts of the hospital. The typical personnel who are utilizing this equipment for patient monitoring have, at best, an average-to-poor background in so far as the technology of the equipment is concerned. At best they simply use the equipment to monitor a display, in the sense of a warning signal if the vital functions of the patient being monitored fall outside some established boundary limits. These kinds of problems may, to some extent, be solved by providing intensive short courses in the operation of the electronics equipment for the medical personnel responsible for its use. The real problem, however, sterns from the lack of personnel responsible for the maintenance, installation and safety hazards which are associated with all types of electrical equipment. In most of the hospitals visited, the usual numbers of such personnel were perhaps one engineer and one technician who were-in charge of the maintenance of much of the electronic equipment in the facility. Obviously, since the number of electronic units in the ICU and CCU units in the typical hospital was quite high the technician or the engineer in charge of the maintenance was able, at best, to simply "hold the line"; that is, keep that equipment operating which was sufficient to take care of emergency problems. In most cases the existing situation consists of a huge backlog of inoperative equipment which is pushed into a holding area (perhaps only a fuse had blown) because the technicians invclved in maintenance are too busy keeping ahead of the emergency services. Additional problems arise from the fact that the hospital staffs usually do not include personnel who have a comprehension, in depth, of the makeup of the electronics devices and equipment. Thus, the medical personnel, as well as the hospital administrators, depend almost entirely on the sales representatives from the manufacturer for an estimate of the specifications for the equipment. A recent article, in one of the engineering trade journals, which involved interviews with several people at two or three of the large midtown hospitals assailed the fact that much of the equipment (up to 80% at some of the institutions) being received does not satisfy the specifications claimed by the manufacturer and in many cases the hazards and safety aspects of the equipment have not been given adequate attention. It is apparently, also a common practice that in many cases salesmen contact individual physicians in the hospital and convince these individuals that they require certain kinds of equipment and that the model being represented is the one best purchased. The hospital then purchases the equipment because of a physician's request and in many cases the proverbial "white-elephant" situation does arise. The hospital staffs desparately need personnel who are very familiar with electronic equipment, especially instrumentation, and who are able to describe specifications for the equipment and to request from the manufacturer specific test procedures to insure that the specifications requested, and/or stated by the manufacturer are, in fact, met. The staff also require personnel whose duties would include the responsibility for the acceptance of incoming electronics equipment (i.e., for calibration and for testing) and a policy could be set up whereby the medical center will not sign for the receipt of any equipment which has not passed through its own in-house testing procedures (this procedure is similar to that, for instance, already in force in the College of Engineering at Stony Brook). Further, the maintenance personnel force, such as electronic technicians with an engineering supervisor, needs to be expanded so that the totality of the electronics equipment in an institution can be maintained at a reasonably level of performance. Here again, the need is great and is immediate in that it cannot be classified as something to be filed away for the future. The problem in this context is also linked to severe budgetary restrictions which makes it very difficult for budget planners, in view of the more conventional medical needs of patients (i.e., hospital beds, medical staff, etc.), to justify using portions of the budget to add to the staff personnel such as the electronics technicians and biomedical engineers and/or engineering specialists for the instrumentation.

An instrumentation faculty was visited which, because of its very advanced nature and mode of operation, deserves special mention; and that is the Department of Medical Instrumentation which was conceived, instituted and developed to its present level of activity by Dr. Seymor Ben-Zvi at the Downstate Medical school (SUNY). In that isntitution Dr. Ben Zvi's group constitutes a full department in the hospital services. The group is staffed by approximately 35 people, five of whom are engineers, some 20 technicians and perhaps 10 others who are administrative and secretarial staff. The department houses not only an electronics-equipment maintenance and repair shop, but also a full-scale machine shop. The facility also performs the function of acting as liaison between the hospital and the equipment manufacturers not only for medical instrumentation but for any equipment which is an electronic or electrical nature and from which hazards might appear. For instance, the group was, at the time of the visit, in session with representatives from the manufacturer of microwave ovens. The ovens were under consideration for the hospital kitchens but Dr. Ben Zvi's group was charged with checking specifications and the testing procedures as stated by the manufacturer; the hospital administration requested his approval before purchases of the equipment were made. In addition to this sort of function, the department provides the facility for general maintenance of electronic instrumentation and for the modification and, perhaps, for the designs of new kinds of instrumentation (i.e. performs a backup function for medical research which might require special equipment to be constructed on site).

In addition, the operating room wing at the Downstate Medical Hospital is arranged so that almost all electronic monitoring equipment in the operating rooms feeds the data to a separate space (within the OR wing) where the computer and other data-reduction and processing equipment is housed. The required outputs are then channeled back to the operating rooms and displayed for the surgeons and the other members of the medical staff. It was explained that the concept of having the sensing equipment in the operating room, with the data reduction being performed in a different space (thus having created the necessity of sending the reduced data back to the operating room) was based on the fact it is very upsetting to patients, if some piece of the equipment needs attention from the technicians, to observe apparent equipment failures taking place, even though these failures may not be of an emergency nature. The operating-room wing at the Downstate Medical Hospital is immediately adjacent to the electronics repair facility and the other facilities of the Department of Medical Instrumentation. Two electronic technicians are kept on call (in scrub suits) outside the doors of the wing, and in the event that an equipment failure does take place they can immediately move into the OR area to effect the necessary repairs. In special kinds of operations, for instance where open-heart surgery is involved, the electronics technicians are placed directly in the operating rooms as part of the OR team. That is, they remain in the opkrating room continuously monitoring the equipment as to its'proper functioning and calibration. Therefore, the medical-instrumentation facility at the Downstate Medical Hospital seems to be one that is very well thought out and is in full operation and represents a model of its kind for medical institutions.

A similar problem, in a different context, exists for the case of the communication probelm in medical centers. This involves not only intercoms and signaling systems, but more especially the information-communication aspect involving the collection of data, its application to the input of the computer systems, date, reduction, the transmission of the information to various parts of the hospital system and finally the ultimate retrival of this information. The aforementioned complaints, regarding the flow of information throught the hospital, here again seems to point out the immediate need for personnel who are able to design from the information-system viewpoint, and for computer specialists (including both the hardware engineers and the software specialists). These are required to help medical centers set up and operate an efficient communication system (it has been stated that the physicians, who were visited, were very consistent in their complaints that, while there is a voluminous amount of data being measured on the patients, once the data gets into the computer system it is extremely difficult for the physician to retrieve a specific piece of data in a language that he can understand).

When one considers the present development of the equipment which is under discussion, and when one considers further the number of personnel who will be required for the whole of the information-system portion of the hospital activity, it becomes obvious that it is unlikely that hospitals, which are smaller than full-scale medical centers, will have within the capability of their budgets the ability to purchase such facilities. In all likelihood, it will make better sense, for the future, that the vast computer facility, data reduction and electronic instrumentation and the attending personnel be, for the most part, centered in the large health-sciences center, in some particular geographical location, and that computer terminals with some relatively, small number of operating/maintenance personnel be located at the various smaller hospitals in the vicinity. The system will make available, to the smaller hospitals such items as research infornation, on-line consultation with a renowned medical specialist and the ability to request loans of special but expensive electronics instrumentation. In regions where there exist large concentrations of hospital centers, a separately-housed center for medical instrumentation and engineering consultation, specifically designed to service the medical centers would seem to make sense. That is, the modification, design, calibration and specification of instrumentation as well as short-course instruction could be attended to by a facility housed in a research center which is located in some area convenient to all medical centers in the particular location. The center may be administered by the Engineering unit at a nearby university center, or possibly by a separate commission set up by the hospitals in conjunction with the local government. Of course, the small as well as the large hospitals could avail themselves of the kind of services that such a facility could perform. As an example, the network of hospitals on Long Island consisting of Nassau Medical Center, Queens Medical Center, LI Jewish Medical Center, North Shore Hospital and our own medical center at Stony Brook certainly could profit from some centrally-located technical facility of the type mentioned above. There is no reason why such a center could not also be involved in an ongoing academic program, say in bioengineering, so that personnel from the academic staff as well as the graduate students, and possibly the undergraduate students, could interact with the personnel who primary function is essentially to service the hospitals. In this manner it may be possible to provide the service staff with backup from the academics and to make it possible for the academic groups to gain the clinical experience which is necessary for the education of bioengineers, that is, those engineers who will specialize in medically-related aspects of the profession.

V. Prosthetics:

The concern with prosthetic devices, from the engineering viewpoint, will most likely be centered within the efforts by electrical and electronic engineers, mechanical engineers and materials engineers. These personnel. will assist with the design, development and maintenance of prosthetic devices of-all varieties. They will also provide a staff which could be employed for liaison between the medical center and the manufacturers of prosthetic equipment. The development of most prosthetic devices requires the combined talents of electrical, mechanical and materials engineers working in very close conformity; in many cases it will be an engineering with a true inter-disciplinary background (say, an electromechanical engineer) who will be most valuable in the design of such equipment. It may be agrued that certain prosthetic devices should be categorized as "Instrumentation" rather than under the present category. In this report, however, the former category is reserved for that equipment which is primarily electronic (except for the sensors); that is, the equipment and facilities which will be the responsibility of electronic and computer specialists. The prosthetic equipment, as referred to herein, consists of pacemakers, kidney dialysis machines, artificial limbs, artificial (internal) organs, and devices which assist the aural and visual senses. Thus, not only electronics is involved but, mechanics, fluid dynamics, hydraulics, and materials are among the other' engineerin aspects pertinent to the subject area.

Here again, the R & D for prosthetic devices may or may not be 'implemented within the medical center itself. Certainly, the motivation (the patient! or initiation of the research exists in the hospital; it is also there that the clinical evaluation of the testing and the eventual use of the final product will reside. However, the earlier stages of design and development may well take place at a central facility administratively, and perhaps geographically, removed from any one particular hospital. The center may, as in the case of the Instrumentation Center previously described, act to service a whole network of institutions.

VI. Physiological Systems:

The activity envisioned for this category may best be described as the modeling and the analysis of complex physiological. systems, in terms of the language of systems and control theory and design. The work will generally be done at a research, or at least at a research and development, level and will probably employ engineers with a graduate degree; either the M.S. or Ph.D. As the field develops it is probable that the personnel who will be active will include almost the entire spectrum of engineering specialists; that is, electrical, mechanical, civil and chemical engineers, and engineers who are a hybrid of two or more of these. The tasks will in most cases fit in the context of a particular research project in the hospital and it is difficult to predetermine a need for such engineering personnel by attempting predictions based on the activity of any particular medical center or group of medical centers. At present, the majority of the engineers who have entered this activity (i.e. have formed research teams with physicians and surgeons) are electrical engineers, especially with regard to the subject area of neuro-physiology. In those projects where body-fluid dynamics or blood-gas experiments are being implemented it is generally chemical engineers and/or mechanical engineers who predominate in the engineering portion of the team. There will need to be a close relationship between personnel who are involved in the modeling of physiological systems, the electronic instrumentation specialists and/or the engineers involved in the design of prosthetic devices.

In many instances, the most immediate contributions which the systems engineers can offer involve the design of models which provide a basis for quantifying the predictions relative to physiological processes. As an example, medical practitioners may have been aware of the indications resulting from the infusion of some medication (say, a muscle relaxant) into the physiological system. However, the prediction relative to this was usually based on previous experience as to what might occur, after some given period of time, following the injection of some known quantity of the medication. The bio-medical systems engineers are now able to model some of these complex systems so that the appropriate analytical expressions can be written and can provide a more percise prediction, for all periods of time, of the effects of having a certain chemical enter the blood stream or a certain drug used in the neural or the muscular system of the human physiology. This activity has already been initiated, and has produced results, at some medical centers.

VII. General Research and Teaching:

This category recognizes all phases of engineering and all the various forms of research teams that might be coalesced for specific projects. The members of such teams will, in all probability, be possessors of the higher academic credentials, usually a doctorate in engineering or in one of the health-related fields. In the efforts cohcerned with the teaching of clinical subject matter the responsible personnel may have a professional degree as well. The engineers in this category will work in close proximity to physiologists, biologists and medical scientists for the development of Fesearch and of curricula, and in the lecturing for the medical centers. It is exceedingly difficult to make predictions concerning the engineering activity in this particular category since the nucleation of these kinds of activities will no doubt take place via some natural proclivity of the personnel an the staff of any particular medical center. The nucleation will also depend on the ability of engineers, already with these staffs, to develop a liaison and to form research projects with the medical personnel as a means of motivating the growth of new subject areas which will, in turn, provide an additional entree, for the engineer in the medically-related professions.

ENGINEERING FOR HOSPITAL SY

It is fairly obvious that not every hospital unit in a particular geographical neighborhood will be able to devote resoSTEMS to all the facilities described in the previous sections. Those hospitals that will employ engineering staffs in the administrative units and the nedical instrumentation units and also have research and teaching facilities will, no doubt, be the large medical centers. The smaller medical units in the area will most likely form part of a large network with the medical center being the locus where most of the electronics, computer machinery, consultants and possibly the overall administrative direction of the network will reside. However, by the appropriate design of the infornation system connecting the parts of the network (i.e., on-line computer services and other means of communications will provide the local meighborhood hospitals, or other parts of the network, with a method for the information that resides in the large medical center and a method of implementing the storage and retrieval of both business and medical information) it is possible to provide the smaller units of the network with the medical knowledge, medical services, high-level consultantions, administrative service and testing services as they exist in the large center. There are also to be considered mobile units; these may be ambulances for emergency services, or mobile units in the neighborhoods performing such functions as health screening, on-spot examinations, application of medication, distribution of veccines, etc. These units will need to be in constant communication with and under the direction of a central administration. Therefore, it is envisioned thatthe future delivery of medical services in a geographical region will probably be represented by a large medical center with communication ties to the various neighborhood hospitals and other medical. centers in the nearby regions. The design of these medical systems will require the attention of large numbers of engineers who have, as part of their backgrounds, the specialities of the information sciences, communication theory, systems theory and design, and also engineers who have the capability for design of the hardware. The work will comprise not only the design of the hospital system per se but the design of communications facilities (in the snese of equipment), i.e., telecommunication and closed-circuit communication equipment, audio-visual equipment and interconnected educational systems throughout the entire network (including the aforementioned mobile units as well as the hospitals and other medical buildings in the distribution of users).

GENERAL RECOMMENDATIONS FOR BIO-MEDICAL ENGINEERING CURRICULA

The discussions at the medical centers did not dwell on the specifics of the design of curricula, but on the aspects of a general flavoring for such curricula for the variety of bioengineering career channels. It was felt that, with regard to the engineers who would be engaged with the design and construction of buildings and with plant maintenance, there is no pressing need that they be exposed to courses in the biological sciences. Rather, courses in hospital organization, patient and medical psychology, and an internship spent in an actual medical facility were considered of greater importance in the training of that particular category of personnel. There are special cases, i.e., air-conditioning engineers, who may need to have included in their training some study of bio-chemistry and of bacteriology. The education of engineers who will be essentially in the third category (of the previous section), that is, in hospital administration, should have their greatest exposure to course work and to internships which feature the administrative organization of hospitals. The activity in hospitals is becoming more and more intertwined with that of the surrounding neighborhoods in which hospitals reside, and there will appear on the administrative staffs personnel who will interact with community affairs and have a roll in bringing the community opinion into hospital activities. These inputs occur, most likely, when plans for new hospital facilities, or modification of existing facilities are made. Such personnel will also be involved with community affairs and all aspects of the work wherein the community feels itself to be affected and serviced by a particular medical network. Here again, the serving of an internship, as part of the student's formal academic career, was considered by many of those with whom conversations were held to be an extremely valuable method of orienting a particular engineering student in the work of a hospital or medical center. For the case of the instrumentation and the communication engineers, and for those engineers involved with the design of prosthetic devices, the opinion was mixed as to whether the present mode of educating electronics or mechanical engineers was sufficient for the need of most medical centers or whether these engineers needed more specialized training for the performance of duties in their biomedical engineering careers. One end of the spectrum of opinion felt that, if, as an example, electronic engineers were to be educated as at present then they could perform adequately the work in hospital centers, or with manufactures of electronic instrumentation and learn the specialities, i.e. aspects of instrumentation specific to biomedical work, during their practice, rather than he exposed to the subject matter in formal courses. However, there were a few opinions that the curriculum changes needed to include some course work in basic physiology, basic biology, work in the animal laboratory and perhaps, some work in organic chemistry. It was felt that if the instrumentation specialist or the communication specialist, or engineers responsible for the design of prosthetic equipment, would have to interact with and assist the physician with the delivery of health services at the patients' bedside, or work with him in the use of instrumentation for diagnostic procedures, then it behooves the instrumentation specialist to have some understanding of the biology and/or the physiology of the specimen under test (i.e., a biological specimen in the laboratory or perhaps the patient himself).

The design of electronic systems associated with communications in the hospital (i.e., radio, t.v., telemetry, telecommunication systems and intercoms) does not necessarily need to be performed by engineers who ere trained with background in the health sciences or life sciences. However it seems doubtful that hospitals will have resources for duplicate staffs; that is, a full staff of electronics engineers who are essentially biological-physiological instrumentation specialists and an additional staff of electronics engineers who are specialists in essentially non-medical electronics. However, there might well be one or two of each kind of engineer present in a particular hospital center. It was felt that in many places some of the duties of these kinds of people had to overlap due to the constraints imposed by hospital budgets. Here again most of the opinions stated were that an internship of some sort, served by engineers in training, was of great importance. It was also mentioned that it would be very difficult for the personnel in the health sciences to feel that a bio-medical engineer had received a creditable education unless that education involved some experience with the animal laboratory.

It was generally felt that it would be profitable for the biomedical engineer to serve his internship either during his undergraduate years or perhaps as a post-graduate activity in a hospital center. This internship could be one in which the engineer becomes involved with the hospital simply to learn the way in which hospitals are organized, or it could be an internship served on a technical project within a field of speciality, i.e., by working with the hospital team in the installation and the operation of electronics instrumentation or with a nuclear-medical-group working with x-ray machines and assisting with the development of the x-ray technology existing in the hospital. The last two categories outlined in the previous. section of this report were those entitled Physiological Systems and General Research and Teaching. In these activities the involvement is usually at the Ph.D. level, although M.S. students or M.S. projects *may* also fit into these categories. Probably, the kinds of curricula developed for these categories will depend primarily on the interests of the faculty at a particular medical/engineering school complex; these would in turn, deternine the kinds of projects which will occupy that faculty and the associated research teams.

It would be difficult, at present, to attempt to formulate a firm list of courses that will be needed to implement the various bioengineering programs. It can be predicted, however, that some future list will include courses 'that will be taught either in the Health Sciences Center or in the College of Engineering; in some cases the courses will no doubt be co-listed and co-administered by the two schools with the faculty interchanging from either direction. A description of an assumed curriculum may envision course sequences, selected from both the College of Engineering-and the Health Sciences Center, which would service the undergraduate and the M.S. program. The same course sequences can be used in conjunction with other courses, for greater depth, and with a wider selection of courses in both areas (i.e. life sciences and engineering), to provide the academic format for the Ph.D. However, the laboratory work and the project work will in all probability be the most significant contributor to the training for the Ph.D. There is no attempt, in the present report, to produce an outline for a series of courses that might be used to construct specific curricula and or a track for bioengineering studies at this university. The purpose of the study and of the present report was simply, as stated earlier, to gather a background of opinions from medical people and to present this data as an additional input to be included with the several studies performed by various institutes, engineering groups and the Academies, as to how bioengineering curricula should be implemented. As was previously brought out the remarks in this report represent the comments and opinions as received in those hospitals that were visited, and to that extent the selection represents a cross-section of, at least how the life scientist envisions the task for engineering in the delivery of health services. This report should be of some value to those who must now develop, using the resources of the engineering and the health schools, a curriculum, or sets of curricula, which will represent programs in the biomedical engineering fields.

I would make the personal observation that the present course offerings at Stony Brook already permit the structure for M.S. programs in Bioengineering, and therefore this degree program will be the easiest to implement at present. Such degree programs can be offered almost immediately, provided that departments are willing to relax any stringent academic requirements which they may have for graduate degrees, i.e. departments must be willing to forego the requirement for the minimum number of courses which students must take in the department, and must be prepared to waive, or to accept substitutes for, certain portions of qualifying examinations, if those portions represent a burden on a student who wishes ti work in a field which is perhaps peripheral to the core material of a particular department. Arrangements as to satisfaction of the requirements for *any* particular degree would have to be part of the discussion regarding the design of future academic programs. However, with the present course structure and the present departmental requirements, a graduate student working for his M.S. in bioengineering should not encounter too great a difficulty provided the department concerned provides an adequate advisory service to those students. The fact that at Stony Brook the faculty in the Engineering College and in the Medical School have already collaborated, in an informal way, on joint projects indicates that there are really no significant boundaries preventing the kinds of N.S. projects that lend themselves to bioengineering training.

In several. of the hospitals visited informal questions were asked concerning the possibility of having students register in courses, designed specifically as internships which could be served in the nearby hospital centers with perhaps a academic advisor at the Stony Brook campus and a co-advisor at the medical institution. The ideas seems to have been favorably received and it was felt by many of the people on the medical staffs that there would, in fact, be an advantage in establishing an interaction of this type. The students could serve their internship either from the viewpoint of learning hospital organization (as already mentioned) or perhaps may work on projects in a more formal sense where they are actually assisting some of the medical people with the technological problems involved with electronics instruments design, x-ray technology, etc. in the hospital center. This work could also serve as a partial fulfillment of the requirements for the degree, either in the sense of course requirements, or in the case where the work is of the appropriate nature for a formal thesis.

PROGNOSIS

It seems clear that, based on the discussions, the personnel in medical centers recognize a need for designing curricula so as to include Bioengineering in the curricula of engineering schools. In terms of career opportunities the most immediately viable programs would seen to be those at the bachelor's degree and at the M.S. degree level. This does not preclude the need for Ph.D. work, but it is likely that medical centers will be very selective about adding the latter personnel to their staffs and thus, for the immediate future, the productivity of Ph.D. recipients in the bioengineering field should not proceed immediately at a very high level. In point of fact even the most optimistic projections being made seem to indicate that the need for bio-engineering Ph.D. 's will never be so large as to warrant having every engineering school (which so desires) produce graduates in this field. It is more reasonable that some few schools, which have the departments of engineering and of health sciences in proximity, be those that are fnvolved in such programs; those engineering schools and nedical schools that lack the nearby counterpart would probably do well not to develop such fields of study in the formal sense. It also seems unwise, at least for the immediate future, to begin a development of bioengineering programs in terms of a completely separate departmental structure; that is, separate faculty, an administrative unit, auxiliary personnel, allocations of laboratory space and coney, and the other peripherals that go with departmental structures. The comments received at the medical schools visited indicate that it probably would be best to develop a bioengineering program that is imbedded in existing administrative units with the identification based on contributions to the program by members of the faculty and with some of the faculty chosen for their reputations in the field, or willing to establish such reputations by a commitment to nucleate academic courses, programs, research and other activity in biomedical engineering. The discussions in the previous section has indicated that there is a large portion of the total engineering spectrum in which the training of the biomedical engineer (i.e., using the term in the broadest sense so to include all engineers involved with some aspect of the delivery of health services) will require perhaps a few courses and an internship involving topics such as hospital organization, rather than studies in the life sciences per se. On the other hand there are types of biomedical engineers, especially those trained for research or, perhaps, for instrumentation, whose training will require a number of courses, not only of the type involving hospital organization and internships but courses in the life sciences such as studies in the biology end the physiology of clinical measurements, the psychology of patients under measurement and the sociological aspects of the problem of testing patients, as well as the basic technology of the instrumentation. Certainly, those biomedical engineers who will be employed in the research and the teaching positions will need training, in depth, in some of the health sciences to, perhaps, the same extent they receive training in the engineering sciences.

It is probable that it will be somewhat easier to implement the M.S. program at Stony Brook, in the immediate future, than either the other two degree programs (i.e. B. Eng. and Ph.D.) simply because, with the advent of a graduate program in the School of Basic Health Sciences there will exist, among the courses offered in that school, in the departments of biology, chemistry, physics and in Engineering a sufficient number to adequately support an M.S. program. The question of developing a suitable thesis project, or an internship project for the M.S. degree would not represent a problem since even at present there have been completed, on this campus, M.S. projects and undergraduate projects which, because of there subject matter, would certainly fit in the category of biomedical engineering. During the discussions with personnel at the medical centers it was suggested that student projects for undergraduate, M.S. and Ph.D. studies could be performed by having students pursue the work either on campus or ,at the medical centers where there could be assigned a co-responsibility for the supervision, i.e., an academic advisor located on campus and a designated co-advisor at one of the medical centers. The latter could keep an account of the student's work at the center and the two might serve as the members of the student's advisory' committee' and thesis committee, along with others. From the viewpoint of the design of cirricula, it is probable that the Ph.D. program will be developed rather eaily. As in the case of most Ph.D. programs, Thesis projects. and course programs usually nucleate because several faculty (who agree to make such commitments) and students (who show interest in the field) vigorously organized a project or series of 'projects which in turn develop, if at all viable, into a full-fledged program. However, the concept of a structured program is not as pertinent for the Ph.D., since the way in which the doctoral student is expected to get his information does not .necessarily depend on a great sequence of courses, but rather he is expected, with his faculty advisor, to select courses as needed to support the work of his research area. It is to be expected that the general type of thesis that might be produced in a bioengineering program will probably have some associated experimental work in order to maintain the status of of value to the medical scientist, who must, ultimately, be the one convinced of the importance of the results. The M.S. program may perhaps contain more structuring, than-in the case of the Ph.D. program, since there is probably a-greater concern regarding satisfaction of departmental course requirements for the M.S. degree than for the Ph.D. degree. However, the situation at present, in most of the departnents, seas to indicate that these requirements are minimal and that the constraint on the student, in selecting courses, is perhaps to the extent of one or two courses. These are usually specified in order to provide the student with sufficient background to pass an examination, require for the degree, Even so, it may be possible to convince departments, having the constraints, that the requirement for the MS be made more selective, in the sense that the student be given a choice amond parts of the examination, where one of the parts might be specifically designed for the student majoring in bioengineering subject area.

In the case of undergraduete programs there is probably a greater need for a stronger structuring in the design of the curriculum. There seems to be the fashion today, even at the undergraduate level, for students to insist that they require a great flexibility in the choice of courses for satisfaction of degree requirements. In spite of this claim it is a fact that many undergraduate students still find themselves uncomfortable (even with an efficient and an available advising program) when they are placed in a non-structured academic program, It still seems advisable'to design undergraduate programs, including the bioengineering programs, so that flexibilities are maintained for those students who do work well in a non-structured situation*and who are able to see their way clearly, and are able to make a selection of courses with advice on the part of the faculty. At the same time there should be visable in the prograus certain tracts, so those students who work better in the structured situation can identify the kind of course sequences that are best suited for their purposes. Here again, in order to maintain some credibility 'in the program it 'does seem advisable to include as part of the undergraduate program some project work and/or an internship which involve the actual experience gained in the animal laboratory and the nedical center. It may happen that the design of the curriculum may not necessarily require the development of very many new courses, but merely the addition of a few new courses to those presently offered by the various departments of engineering and of the life sciences. Thus, faculty advisors may find it possible, by taking selections from presently - offered courses and from the new additions to construct a program which, together with a suitable project and a project advisor, will result in a reasonable program leading to the appropriate undergraduate degree.

The present undergraduate engineering program certainly has in its content a large number of open technical electives as well as non-technical electives, which would permit the student to select a sufficient number of courses for the satisfaction of a program which is designed for specialization in bioengineering. It might also be useful to note that the selection of courses in such a situation might satisfy two purposes achieving the B. Eng. degree in bioengineering and/or satisfying pre-medical school requirements. A particular student might wish to use the undergraduate engineering program as the means-for a premedical education and the two objectives can be combined, i.e., the undergraduate program for that student may be designed in a manner by which he simultaneously satisfies the pre-medical requirements and also has gained an undergraduate degree which is a suitable credential for work in the bioengineering field. As an example, the Department of Electrical Sciences may advise a student to develop his bioengineering program by the use of present undergraduate electives (which give a sufficient choice in the fields of electronics, general instrumentation, control system, elementary communications, digital circuits and data processing) and the inclusion in his electives, of new specifically designed courses such as biomedical-engineering control and communications systems, biomedical instrumentation, advanced biomedical instrumentation and

and biological systems modeling. This selction can be incorporated with courses given in the departments of biology, of physiology, of chemistry, as well as with courses in the other engineering departments. The details of the program, in terms of actual course descriptions, syllabi and course structures, need to be worked out by the administrative units and the joint committees among the engineering departments and the departments in the life sciences.

As mentioned in the beginning of this report, the present study reports on the conversations held at nearby medical centers and does not include, except indirectly, the industrial aspects of biomedical engineering. The number of biomedical engineering graduates who eventually find careers in the medical centers will probably be a number much smaller than those who find their careers in industrial centers which are involved with biomedical engineering products; that is, those industries which design, fabricate and supply equipment to the medical centers. These products include electronic instrumentation,. prosthetic devices and electrical and mechanical equipment for the hospital plant. However, many of the comments in the present report apply equally well, in the opinion of the author, to those engineers who will eventually find their careers in industrial institutions rather than in medical centers. That is, 'the training which makes an engineer suitable, for example, aa an instrumentation expert for a medical center will make him just as suitable as an instrument designer for an industrial activity. Those students who can decide, beforehand, which of the two options they wish to select for their future careers, may flavor (by choice of electives) their undergraduate programs so there is some recognition that one particular program reflects a greater interest in industrial work whereas some other student who might choose his courses in a manner which directs him toward work in a medical center. That is, the former student might select his electives so that they are heavier in the hard-.core engineering curricula whereas the latter student might select his courses more heavily from the life sciences.

The one point that cannot be stated often enough, nor stated strongly enough, is the enormous advantage which the present situation at the Stony Brook campus lends to the development of the bioengineering programs. It would appear that at many engineering schools, the difficulty in establishing viable bioengineering programs stems from the condition that although the schools claim to have work in the bioengineering field they are either not associated with a medical school, or the medical school of that particular university is located so distant from the engineering school as to preclude having the interaction between the two schools be a natural, and one which maintains the enthusiasm of the faculty and the students. A consistent remark heard from medical personnel is that no bioengineering program could be expected to maintain its credibility that did not involve sane clinical experience. It is apparent that the Stony Brook campus is the only campus in the New York City - Long Island region that does have the engineering school and the medical school in proximity on the same site. The advantage which accrues is enormous; the faculty from the engineering school, the health sciences center and the life-science departments interact in a natural way, i.e., by serving on similar university committees, meeting socially and meeting formally (and informally.) in many activities associated with running the university. This advantage is one which argues very strongly for the need to develop bioengineering studies at this campus. For example, if a decision were to be made that, because of the expense and because of the wish to maintain some control over the number of graduates which are produced, not every engineering school were to he permitted to develop an extensive bioengineering program, then it would seem that one of the prime schools to be selected for this subject area, especially, should be the campus at Stony Brook. One additional point to be made is the suggestion that future program directors monitor, very carefully, the career opportunities which exist in the bio-engineering field so that, as graduates leave the campus and move into their careers, there is maintained a very tight feedback arrangement which provides up-to-dete information as to how readily the graduates are finding career opportunities and whether they *are,* in fact, utilizing the educational background that is provided for them. It will then be possible to maintain a constant supervision over the modification of the existing programs so that they can be continually adjusted to meet the changing needs of the bioengineering field. There should not be an a priori decision that society needs bioengineers which then leads to the production (in an uncontrolled manner) of engineers in the subject area, without some concern of the career opportunities, or lack thereof, which exist at some point in time. There should not be repeated the exercise, that has occurred in several subject areas where, because of the strong feeling for the-importance of an area at some particular time, schools were allowed an unlimited expansion based on the interest of the students ox of the faculty, only to find that in a few years the area became saturated and/or unpopular resulting in an oversupply of both faculty and other professionals in that career area. In closing, the author recommends that the administrative units on campus direct committees to begin the design of academic plans for bio-engineering work at the undergrate, the MS and the Phd levels; and that this not be implemented by an immediate creation of a department or separate administrative unit but in the context of the present departmental structures. However, the designs of the curricula should be made visible, i.e., a pamphlet and catalog material be published so as to indicate the presence of bioengineering programs and to describe the tracks within the programs. The information should also inform prospective students as to academic advisors. Of course, it is also pertinent that the name of the faculty be identified who will agree to make commitments to the subject area, and that faculty recruitment for the task include the people who have already established reputations in this area as well as those who show potential for the development of academic programs in bioengineering.

ACKNOWLEDGEMENTS

The people who assisted the author during his visits to the various medical centers are certainly too numerous for all to be mentioned, However, certain staff members, at the various medical centers, gave their special attention to the visits and a considerable portion of their valuable time to discussions. The author wishes to acknowledge this effort, and to be re-emphasize that the opinions in the present report are not necessarily the opinions expressed by any one or combination of the persons mentioned, but represent a compendium of opinion and the interpretation of that opinion. The data was obtained not only in conversations with those mentioned in the following paragraph but also with the many members of the staffs, at large, in the hospitals. Certain contributions to the opinions were gathered via visual impressions, as it were, that the author received.

The author wishes to express his special appreciation and gratitude to the following (in the chronological order of the visits):
Long Island Jewish Center - Dr. Robert K. Match, M.D., Director; Mr. Joseph Alcobies, P.E., Director of Engineering Planning. Nassau County Medical Center - Dr. James F. Collins, M.D., Superintendant; Mr. Jacob Sarfaty, Electronics Engineer; Dr. Morton Heller, Hospital Physicist, Department of Radiation Theraphy; Dr. Costas Lambrew, M.D., Head of Department of Cardiology. The Queens Hospital Center - Mr. Robert A. Vitello, Executive Director. Mount Sinai School of Medicine - Dr, George James, M.D., President and Dean; Mr. Milton H. Sisselman, Vice-Pres. for Coordinating and Planning; Mr. Kenneth Richman, Administrative Architect; Miss Rosemary Tetrault, Planning Associate; Mr. Burt Hurwitz, Administrative Assistant; Dr. David N. Reps, Director of Management, Engineering Services, S. D. Lizoff & Co. Albert Einstein College of Medicine - Dr, L. C. Scheinberg, M.D., Dean; Mr. Charles Harris, Assistant

Director of Admissions; Mr. Gary Aiden, Assistant Administrator, College Hospital; Mr. A. Silverberg, Director of Supporting Services; Mr. Michael Kove, Associate Director of the Bronx Municipal Hospital; Dr. H. Vaughn, M.D., Dept. of Neurology; Mr. Victor Klig, Interdisciplinary Electronics; Dr. Vahe Amassian, M.D., Dept. of Physiology Dr. Philip Aizen, M.D., Phd., Dept. of Biophysics. New York University Medical Center - Mr. Erwin G. Wilmot, Assoc. Director of Hospitals and Hospital Services; Mr. Peter Hughes, Assistant to the Director; Mr. Raymond Cornbill, Director of Long Range Planning; Mr. William Hanlon, Business Manager; Mr. Alvin Bicker, Instructor in Physiology; Mr. James A. Murrell, Director of Plant and Maintenance. Columbia-Prebyterian Medical Center - Dr. Paul Marks, M.D., Vice-Pres. for Medical Affairs; Dr. William Nastuk, Phd., Professor of Physiology; Dr. John Kinney M.D., Dept. of Surgery. The New York Hospital - Dr. E. Hugh Luckey, President; Dr. August Groeschel, M.D., Vice-Pres.; Mr. F. Cassidy, Business Manager (Cornell University Medical School). Downstate Medical center, SUNY - Dr. Calvin H. Plimpton, M.D., President; Dr. Seymour Ben-Zvi, Sc.D., Chairman, Department of Medical Instrumentation.