Academic Program Models for Undergraduate Biomedical Engineering

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Abstract— **There is a proliferation of medical devices across the globe for the diagnosis and therapy of diseases. Biomedical engineering (BME) plays a significant role in healthcare and advancing medical technologies thus creating a substantial demand for biomedical engineers at undergraduate and graduate levels. There has been a surge in undergraduate programs due to increasing demands from the biomedical industries to cover many of their segments from bench to bedside. With the requirement of multidisciplinary training within allottable duration, it is indeed a challenge to design a comprehensive standardized undergraduate BME program to suit the needs of educators across the globe. This paper's objective is to describe three major models of undergraduate BME programs and their curricular requirements, with relevant recommendations to be applicable in institutions of higher education located in varied resource settings.**

Model 1 is based on programs to be offered in large research-intensive universities with multiple focus areas. The focus areas depend on the institution's research expertise and training mission. Model 2 has basic segments similar to those of Model 1, but the focus areas are limited due to resource constraints. In this model, co-op/internship in hospitals or medical companies is included which prepares the graduates for the work place. In Model 3, students are trained to earn an Associate Degree in the initial two years and they are trained for two more years to be BME's or BME Technologists. This model is well suited for the resource-poor countries. All three models must be designed to meet applicable accreditation requirements.

The challenges in designing undergraduate BME programs include manpower, facility and funding resource requirements and time constraints. Each academic institution has to carefully analyze its short term and long term requirements.

In conclusion, three models for BME programs are described based on large universities, colleges, and community colleges. Model 1 is suitable for research-intensive universities. Models 2 and 3 can be successfully implemented in higher education institutions with low and limited resources with appropriate guidance and support from international organizations. The models will continually evolve mainly to meet the industry needs.

Index Terms— biomedical engineering education; program models; curriculum design

I. Introduction

The population of the world is continuously increasing. It is interesting to learn that the life expectancy is also moving to higher levels globally. Most people encounter serious healthcare problems in later segments of their life. These factors create huge demand for growth of medical devices for disease diagnosis, therapy and rehabilitation. As a logical consequence, the demands for undergraduate and graduate Biomedical Engineering (BME) programs are also consistently growing. There is certainly a need to develop suitable BME educational programs to meet the surges in the demands of the biomedical industry experiencing proliferations of their products. Appropriately trained human resources in the BME field are absolutely necessary for balanced coverage in the biomedical engineering field. The requirements for human resources in BME vary depending on the presence of medical device manufacturing industry in a given country or region. The requirements are also somewhat linked with the classification of countries as low, medium and high resource nations. There are numerous entry-level BME jobs at the international level. These markets have created surges in the undergraduate BME programs worldwide. One model curriculum will not necessarily fit all the BME programs. The objective of this paper is to describe three different models of undergraduate BME program and their curricular requirements, with recommendations to apply them in institutions of higher education depending on national or regional needs.

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II. Background

Traditional Bachelor of Science (B.S.) degrees in engineering disciplines such as electrical, mechanical, chemical followed by electronics, communications, environmental, manufacturing and materials have been in existence for several decades. However, B.S. programs in BME have been growing in countries with low and medium resources only over the last decade.

This study is based on review of several versions of BME curricula in US universities and colleges, which are followed to a great extent in many countries such as Canada, Australia, Singapore, China, Mexico, Malaysia and many other countries. In a typical B.S. (BME) program, students take courses for four years. In a given semester of four to five courses, students take courses with typically 3 credits (3 hours weekly) for Lectures. Lab courses typically have 1 credit corresponding to two to three hour labs. There are numerous variations in the programs in terms of number of years of study, number of credits required, co-op or internship requirement, special tracks of concentration, undergraduate research experience requirement, study-abroad or service learning requirement combination with pre-professional programs, etc.

III. B.S. (BME) Curriculum Design

Several factors need to be taken into account in the program: main career paths, bioengineering content, the extent of common curriculum, relative focus on theory vs. practice, and the relative effort to expend on undergraduate vs. graduate education. The principal goal should be to produce adaptive experts that can respond to new technologies and new situations when changing jobs [1]. Significant variations occur from one BME program curriculum to another. The variations are beneficial to students since industry maybe looking for different skill sets and knowledge base. However, the core program must be consistent with requirements of ABET or other accreditation agency if the program seeks such accreditation. Thus, some common attributes are needed to specify minimum basic characteristics of a biomedical engineer. It has been stated that all undergraduate programs should come to agreement on a core of material that should be taught to all biomedical engineering undergrads, considered as key concepts [2]. Programs can then build out the rest of the curriculum in unique ways that take advantage of their local strengths and their perceptions of the future of the field.

The Biomedical Engineering program requires basic preparation in fundamental courses of mathematics, physical and life sciences. Courses such as Calculus, Physics, Chemistry and Biology are recommended and must be completed within the first two years. The students are also required to get deeper knowledge in two or three disciplines in engineering in order to learn and gain expertise in the multi-disciplinary BME.

While designing a comprehensive biomedical engineering curriculum, the key areas considered in traditional programs are biomedical instrumentation, biomedical sensors, biomechanics, biomaterials, orthotics and prosthetics, rehabilitation engineering, biomedical imaging, clinical engineering, biosignal processing and modeling, medical informatics, etc. [3]. Another grouping reported by the Whitaker Foundation includes biomechanics, biosystems, bioinstrumentation, cell/molecular engineering, and biomaterials.

Core courses in BME must be clearly defined, as this will lay the foundation for the student in the focus BME courses and in the biomedical field. Special Elective and Advanced courses in BME may be included based on available faculty expertise, infrastructure, labs, graduate programs and ongoing research projects [4]. Program must be dynamic to include emerging areas in BME. Students are required to do at least two semesters of Capstone courses. Inclusion of cooperative experiential learning is highly recommended [5].

The REU students develop an interest in the process and methods of engineering education research; in many cases, they made significant contributions to the development and/or classroom evaluation of course materials. They also simultaneously learned a specific program of biomedical engineering in depth. REU paves the way for graduate work in biomedical engineering and entrepreneurial ventures.

IV. UNDERGRADUATE BME CURRICULUM

A. *BME CURRICULUM MODEL I*

Model I of the undergraduate BME curriculum is based on BME programs at large, research-intensive universities. The curriculum is divided into basic sciences, mathematics, engineering, computing, core and focus areas in BME, humanities, social sciences and free electives. Focus areas depend on the institution's research expertise and training mission. Some universities that follow this model are Johns Hopkins University, Georgia Tech., Duke University, University of California San Diego, Boston University, etc.

Following the completion of the undergraduate program, a substantial percentage of students go for graduate studies in BME, Medicine, Law and to MBA program after a couple of years of work experience.

B. *BME CURRICULUM MODEL II*

Model II of the undergraduate BME curriculum is common at institutions that are teaching intensive colleges. The model, similar to Model I, includes basic areas of sciences, mathematics, engineering, computing, BME core and focus areas, humanities, social sciences and free electives. However, the focus areas are limited due to several reasons, namely, faculty, graduate students and funded research constraints. As an example, in one program, the focus areas chosen are medical devices and systems and clinical engineering. Co-op/Internship is also required and can be completed in hospitals, medical companies and other hosts [6, 7]. Several institutes that follow Model II are WIT, NJIT, MSoE, Drexel, UConn and RIT.

The information on the ABET accredited undergraduate Biomedical Engineering or Bioengineering programs can be found from ABET Database, Whitaker Foundation Database, American Society of Engineering Education Database, and in the relevant webpages of individual universities and colleges offering undergraduate biomedical engineering and bioengineering program.

C. *BME CURRICULUM MODEL III*

Model III is set up such that the students are trained to work as BME Technologists in the field. Typically students earn an Associate Degree in Engineering or Engineering Technology and then proceed to a bachelor's degree in Biomedical Engineering Technology. This is equivalent to Polytechnic Programs. The Associate degree recipients are trained to work as BME Technicians in the initial stages. In the subsequent two years, the students are trained to be BME's or BME Technologists. Models of this sort are generally followed in programs offered by IUPUI, DeVry University, etc. In order for students to transfer to a BME Program, students have to take Calculus-based courses as in Model II – type programs.

The biomedical engineering requirements in higher education institutions in low-resource countries are very different due to lack of manufacturing, research and development activities. In these countries, a modified version of Model III may be adopted. Based on the actual needs in the field, a larger share of laboratory courses and hands-on work are considered. Project work to meet the needs in local hospitals will be beneficial to the students as well as to the hospitals and clinics. With regional end-user involvement, partial funding could be sought from available resources. Top students in the program may transfer to BME Engineering programs if they wish to pursue graduate studies or be involved in research and development activities. These students may transfer to universities or colleges offering Model I or Model II BME programs at other countries. Bulk of the graduates from universities offering Model III programs can handle large portions of the hospital clinical engineering work very effectively. Complex equipment systems can be handled through special service contracts.

V. Results

The author has extensive experience in biomedical engineering students using all of the proposed models at various universities and colleges. BME programs conforming to Model I structure were conducted at the University of Rhode Island, University of Miami and NTU in Singapore. A significant amount of time and effort was spent in developing Model II - type program at Wentworth Institute of Technology. Varied interactions were made for the Model III programs in Southern Illinois University, Ngee Ann Polytechnic (Singapore) and Bunker Hill Community College in Boston.

A few programs in India, France and England were studied based on collaborations and interactions with students from the specified countries. Models are related to research-intensive factors, doctoral and post-doctoral programs and available research grants.

In the following section, samples of credit distribution in the three different BME curriculum models are provided in Figures 1-4 and Tables 1-2.

A. BME Model I for Research-Intensive Universities

TABLE I. BME Credits distribution for Research-Intensive Universities

Area	Credits	Total Credits	%
Math	18	136	13%
Sciences	20		15%
Engineering	24		18%
Biomedical Engineering	50		37%
Humanities/Social Sciences	24		18%

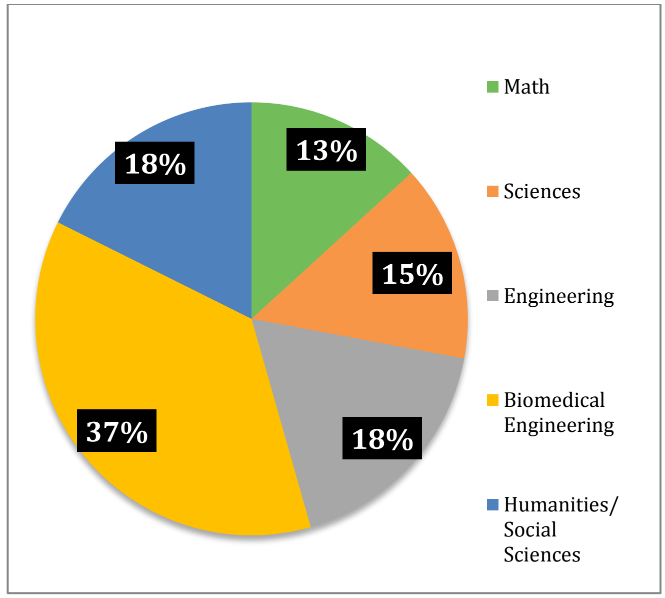

Figure 1. Credit distribution for Model I Universities

B. BME Model II for Teaching-Intensive Universities

TABLE II. BME Credits distribution for Teaching-Intensive Universities

Area	Credits	Total Credits	%
Math	16	134	12%
Sciences	28		21%
Engineering	23		17%
Biomedical Engineering	39		29%
Humanities/Social Sciences	28		21%

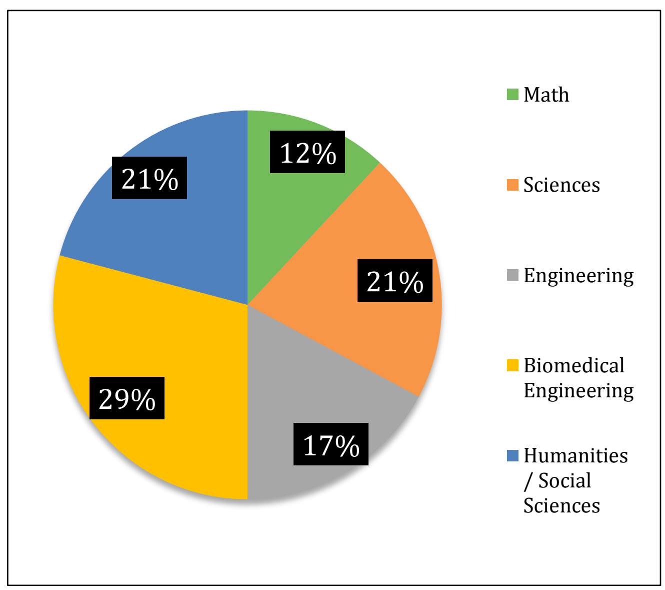

Figure 2. Credit distribution for Model II Universities

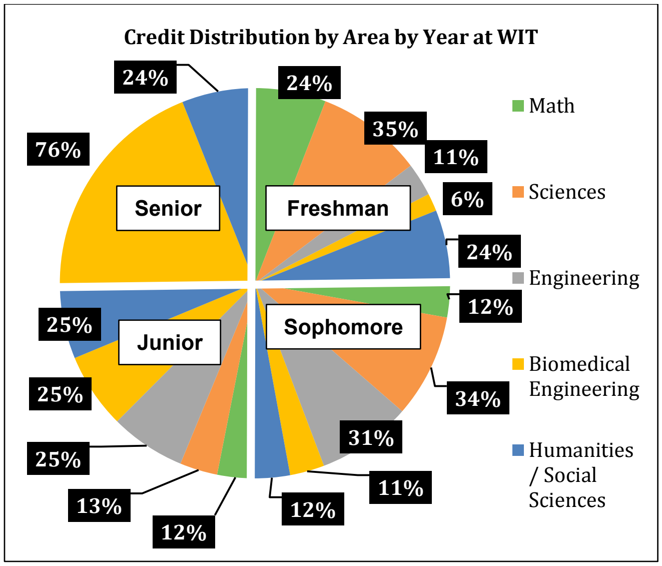

Figure 3. Credit distribution for Model II Universities

C. BME Model III for Continuation from Associate Degree

TABLE III. BME Credits distribution for Teaching-Intensive Universities

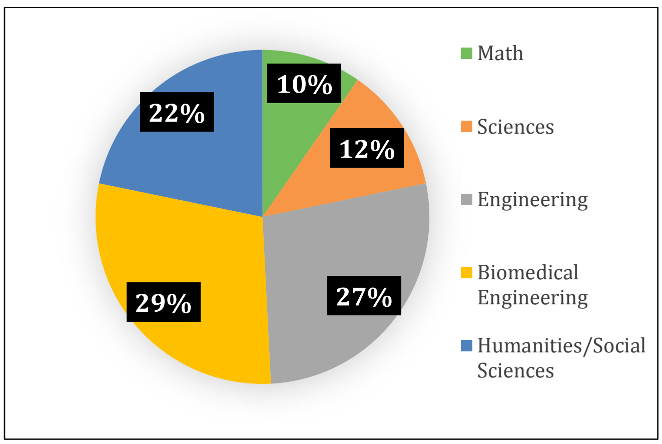

Figure 4. Credit distribution for Model III Universities

VI. Discussion

The average percentage of the total credits for each area for the three presented models are: Math 12%, Sciences 16%, Engineering 21%, Biomedical Engineering 32% and Humanities/Social Science Electives 20%. Variations are adopted in the institutions to suit the faculty expertise, institutional goals and emerging trends.

Graduation rates are higher in Model 1 followed by Model 2. Larger percentages of graduates from Model 1 pursue higher studies. Model 2 and Model 3 graduates fill most entry-level BME positions. Model 3 students tend to take more than 4 years and sometimes up to 6 years to complete the program. Also common in many schools is an Engineering major (such as Electrical Engineering or Mechanical Engineering) with a concentration in BME. Concentration may require students to take more courses (more credit hours) [8]. Some universities have a five year B.S.+M.S. Program (similar to European). In all models, meeting accreditation requirements will be an institutional priority.

Some challenges include manpower, facility requirements, funding for program development and sustainability, time constraints, attracting and retaining good students and recruiting dedicated faculty. Institutional, Regional and National requirements need to be met. Market demand is an important factor for undergraduate and graduate level. Following globalization, graduates can seek jobs available worldwide.

Human resource development starts with undergraduate training. Rapid technological advancements and applications to the medical field necessitate BME graduates to have continuing education and life-long learning. Many organizations have funds for staff career growth and pay for graduate studies.

VII. Conclusion

In conclusion, three models for BME programs are described based on large universities, colleges, and community colleges. Model 1 is suitable for research-intensive universities. Models 2 and 3 can be successfully implemented in higher education institutions with low and limited resources with appropriate guidance and support from international organizations. The models will continually evolve mainly to meet the healthcare delivery market needs and biomedical industry demands.

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