Biomedical Engineering Undergraduate Courses

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Abstract - **Biomedical Engineering is normally included in graduate programs in almost every country where this activity is undertaken. It is thus normally associated with research activities or graduate extension programs. However, some countries (Brazil included) are starting to question the need to include Biomedical Engineering in undergraduate courses, since there is an increasing demand for qualified professionals among the manufacturers of medic and odontological equipment, health care facilities (specially hospitals), testing and calibration laboratories, as well as performance and safety certification for such products. Universities also have an increasing need for such professionals for researching in Biomedical Engineering. This work intends to present some of the current conditions and needs for teaching Biomedical Engineering in several countries, including those considered "first world" and "emerging countries", with special emphasis on the Brazilian situation, both in the undergraduate and the graduate level. Professional needs and demands are presented, as well as the requirements and restrictions for the officialization of the profession of Biomedical or Clinical Engineer in Class Associations. Finally, a critical and comparative analysis is presented, providing a responsible reflection about the convenience, the feasibility and the prospects of Biomedical Engineering as an undergraduate course, with special emphasis on Brazilian needs and conditions.**

Index Terms – Biomedical Engineering, Brazilian condition, Professionals, Undergraduate Course.

INTRODUCTION

Biomedical Engineering (BME) is an essentially interdisciplinary area in Engineering, normally included in graduate programs in almost every country where this activity is undertaken. It is thus normally associated with research activities and programs ("stricto sensu") or graduate extension programs ("lacto sensu").

However, some countries (Brazil included) are starting to question the need to include Biomedical Engineering in undergraduate courses, since there is an increasing demand for qualified professionals among the manufacturers of medic and odontological equipment, clinical analysis products, health care facilities (specially hospitals), testing and calibration laboratories, as well as performance and safety certification for such products. Universities also have an increasing need for such professionals in research teams, in all four sub-areas of Biomedical Engineering: Bioengineering, Biomedical Instrumentation, Clinical Engineering and Rehabilitation Engineering.

This work intends to present some of the current conditions and needs for teaching Biomedical Engineering in several countries, including those considered "first world" and those considered "emerging countries", with special emphasis on the Brazilian situation, both in the undergraduate and the graduate level.

Professional needs and demands are presented, as well as the requirements and restrictions for the officialization of the profession of Biomedical or Clinical Engineer in Class Associations.

Finally, a critical and comparative analysis is presented, providing a responsible reflection about the convenience, the feasibility and the prospects of Biomedical Engineering as an undergraduate course, with special emphasis on Brazilian needs and conditions.

BIOMEDICAL ENGINEERING

Biomedical Engineering is an area within Engineering which uses and applies knowledge, methods, processes and technologies from Exact Sciences and Engineering towards aiding the solution of problems from Biological Sciences and Medicine. When taken in a broader definition, Biomedical Engineering certainly will present intersections with other multidisciplinary areas of knowledge, such as Biomechanics, Medical Physics, Biomathematics and Biomedical Informatics. The definition of Biomedical Engineering per se already implies its multidisciplinary nature, typically involving engineering, physics, mathematics, biology and medicine, the vastness of its possible applications notwithstanding.

Biomedical Engineering may be divided into four main sub-areas:

- Bioengineering: sub-area pertaining specifically pure research, such as the study of neurons and cardiac cells with the help of mathematical models and simulations.
- Medical Engineering or Biomedical Instrumentation: sub-area pertaining the study, idealization, conception, project, development, testing and clinical evaluation of medical equipment (nowadays this is mostly electro-electronics), sensors, transducers and electrodes to be used in the biomedical field.
- Clinical Engineering or Hospital Engineering:_sub-area pertaining activities related to the hospital environment, including design, adaptation and execution of hospital facilities, assistance in decision making processes regarding equipment acquisition, training and orienting maintenance crews and hospital staff, as well as calibration, testing and certification of medical equipment to be used in health care facilities.
- Rehabilitation Engineering: sub-area pertaining the improvement of life conditions for handicapped people.

An exemplary area of application for Biomedical Engineering is the one related to medical imaging, a field where much extremely useful research is still needed towards obtaining better identification of anatomic and physiologic structures in living beings, developing sophisticated medical equipment, processing medical images to be used in the diagnostic process and follow-up of medical treatments and improving the quality of care for the handicapped through modern laboratories for the study of movement.

It is important to emphasize that in the seventies the application of Biomedical Engineering was expanded to include public health sectors and collective health sectors, creating what could be called a fifth sub-area: Health Systems Engineering. However, such activities are still normally classified as a part of Clinical Engineering.

The sub-areas also intersect frequently, as is the case with the development of electronic and mechanical systems present in orthetics, prosthetics and wheelchairs, an evident intersection of Biomedical Instrumentation and Rehabilitation Engineering.

Although Biomedical Engineering is a fairly recent specialization, it has contributed substantially to biomedical sciences. The use of technology applied to biomedical problems is a good example. Besides the evident contribution to health care, Biomedical Engineering also contributes to the scientific, economic and social development of our country by developing professionals from varied backgrounds which are up-to-date in scientific and technical advances to be applied in the frontier of knowledge, both in science and in technology.

Moreover, despite Biomedical Engineering, as so defined, being a relatively recent area of study both in Brazil and globally (it is not more than 50 years old around the world), it has been applied to Medicine for centuries [1]. Consider stethoscopes, for instance. Since the mid-seventies, however, medical professionals around the world started to consider the use of all four sub-areas of Biomedical Engineering indispensable to their activities, due to the enormous evolution in both technology and Engineering methods that has taken place in the past two decades.

Progress in technology is the father of modern clinic health care, based above all in the observation through instruments. There has been enormous technological advance in all areas of Medicine; now instead of treating the consequences of diseases, we expect their causes to be the target of technology.

EVOLUTION AND CURRENT SITUATION OF BIOMEDICAL ENGINEERING COURSES

The evolution and current situation of Biomedical Engineering Courses must be considered from the standpoint of countries designated as "developed" and from the standpoint of other countries, separately. In "first world" countries undergraduate Biomedical Engineering courses have been offered for decades. Harris, Bransford and Brophy have published an excellent review about Teaching Biomedical Engineering in 2002[2]. It is certainly a reference paper, obligatory to all who wish to idealize, implement, evaluate and improve an undergraduate Biomedical Engineering course. The paper reports, for example, an expressive growth of programs, enrollments and graduates over the 24-year period, as described in Table 1, and shows the evolution of the BS programs (or similar baccalaureate programs) and PhD programs in Biomedical Engineering for the past four decades in Figure 1.

TABLE 1
Comparison of Biomedical Engineering Programs:
1973-1999

Program		1973[a]	1999[b]
Bach.	Number of programs	24	62
	Current enrollment	852	5546
	Ave. Enrollment/prog.	36	89
	Grads	38[c]	952
M.S.	Number of programs	37	71
	Current enrollment	505	1106
	Ave. Enrollment/prog.	14	16
	Grads	87[c]	452
Ph.D.	Number of programs	38	74
	Current enrollment	412	1967
	Ave. Enrollment/prog.	11	27
	Grads	49[c]	245

a1973 data reported in Reference [3].
b1999 data from Whitaker Summit summary [4].
cAverage of graduates from 1965 to 1973.

Figure 1 also shows that BS and PhD courses follow the same profile, with only a somewhat constant difference between the two curves in certain periods and around four years of delay from the first PhD programs to the BS programs [4].

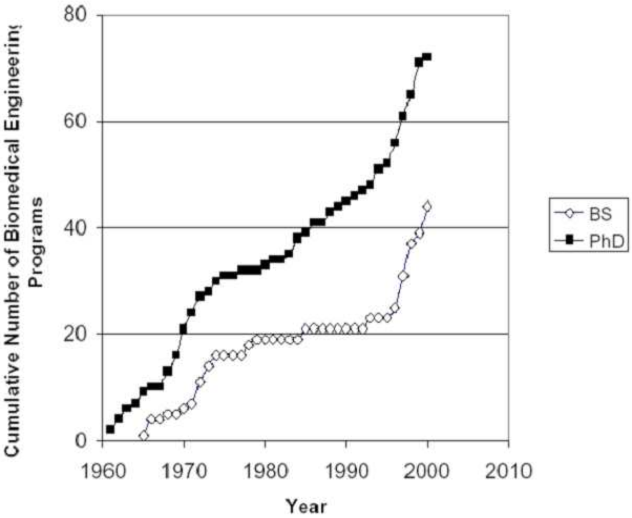

Figure 1. BS and PhD programs in Biomedical Engineering [2]

Moreover, Figure 1 also shows that the rate of growth in Ph.D. programs has been relatively constant over the 40-year period . However, after an initial enthusiasm, the rate of growth in B.S. programs remained low (less than one year average) since 1975 until about 1995. Since 1995, the number of B.S. programs has almost doubled. This is an absolute exception worldwide, however, since very few countries have started offering undergraduate courses in Biomedical Engineering that long ago. We must also consider that courses in this area of Engineering have been offered in the US since the sixties. The current situation may be summarized by the statement that the vast majority of countries has not yet consolidated the offer of undergraduate courses in BME, specially in the southern hemisphere, where most countries still restrict teaching Biomedical Engineering to graduation levels.

In Brazil the offer of undergraduate BME courses is incipient. Early in 2006 the Biomedical Engineering Brazilian Society has shown concern about the need to build human resources in Biomedical Engineering in the country and formed a taskforce to evaluate the conditions, needs and offers found in undergraduate courses in Biomedical Engineering in Brazil. The results were presented in the XX Brazilian Biomedical Engineering Congress, in the city of São Paulo, Brazil, in October 2006 [5]. The president of the Society at the time was the author of this article. The taskforce concluded that there are only three Engineering Faculties offering undergraduate courses in the area, none of which has yet graduated their first class. One of the courses was still enrolling its first applicants and the only course already under way was taught as part of a Biomedical Science course. Considering Brazil's immense territory, it is reasonable to affirm that there are practically no undergraduate BME courses in the country. As a result, the taskforce was assigned the job of suggesting the guidelines to be adopted by any Graduation Institution which may decide to create an undergraduate BME course. Such guidelines were presented in a specific session in the XX Brazilian Biomedical Engineering Congress, organized as a round table. The session had a strong impact on the technical, scientific and business communities present.

It is imperative to perform a detailed, both qualitative and quantitative, study of regional needs for BME professionals and to offer undergraduate BME courses only where such need is guaranteed.

Finally, it is necessary to emphasize the need for market research in short, medium and long term scenarios, considering the possibility of saturation in the demand for such professionals as well. To exemplify, São Paulo currently has a hospital and medical equipment plant capable of admitting 40 professionals per year for certain. However, the possibility of saturation in such a market will depend heavily on the regional economic growth.

WORK MARKET IN BIOMEDICAL ENGINEERING

Before idealizing an undergraduate BME course it is essential to check the workplace conditions in the market that is supposed to absorb the professionals in all four sub-areas of Biomedical Engineering. The situation is consolidated in the US, for instance, which explains the large number of undergraduate BME courses in that country. However, such situation is not observed in the majority of countries, including the ones called "emerging countries".

The Brazilian market currently offers a reasonable demand for such professionals only in a few specific regions of the most developed states, and there are no conditions to absorb such professionals in the other regions. The more developed regions have a significant need of BME professionals since, as stated in Introduction, there is an increasing demand for qualified professionals among the manufacturers of medical and odontological equipment, clinical analysis products, health care facilities (specially hospitals), testing and calibration laboratories, as well as performance and safety certification for such products. Universities also have an increasing need for such professionals in research teams, in all four sub-areas of Biomedical Engineering: Bioengineering, Biomedical Instrumentation, Clinical Engineering and Rehabilitation Engineering.

During the aforementioned round table conducted at the XX Brazilian Biomedical Engineering Congress, researcher Jose Wilson Magalhaes Bassani (PhD.) presented the panel titled "Education in Biomedical Engineering CBEB2006, detailing the evolution and current situation of BME courses in the US and in Brazil, concluding with the following questions and concerns to be answered by the education and professional BME Brazilian communities:

1. How many Biomedical Engineers should Faculties graduate every year?
2. Where will those new Biomedical Engineers be directed professionally?
3. What should be the curricular structure of an undergraduate Biomedical Engineering course?
4. What is the ideal relation between depth and scope covered? This question is based on the finding that most large companies would rather hire an Electrical Engineer, considering it safer. This also happens due to lack of knowledge of what a Biomedical Engineer is. A Biomedical Engineer cannot be a testimony against his own profession, as we have seen in other areas of Engineering.
5. What precaution should be taken against the creation of "Biomedical Engineering Companies" which will offer services through under-capacitated employees instead of qualified Biomedical Engineers?
6. Who will form Biomedical Engineers? To assume that Biomedical Engineering is performed by grouping people from different areas together is the same as stating that Biomedical Engineers are not necessary.

The researcher concluded with the following recommendations:

1. It is necessary to establish a policy for the insertion of Biomedical Engineering professionals in the workplace;
2. It is necessary to define rules and procedures for the acceptance of undergraduate programs in Biomedical Engineering;
3. It is always necessary to develop graduate programs in both Master and Ph.D. levels before implementing undergraduate programs in Biomedical Engineering;

4. It is necessary to define a curricular structure for Biomedical Engineering in order to ensure all sub-areas and specialties are considered, but also to ensure that basic disciplines and laboratorial content are prioritized;
5. It is necessary to avoid the serious mistake of considering the multidisciplinary needs of BME will be met simply by "grouping" professionals from varied and different areas.

The author of this paper not only agrees with such questions and recommendations, but also emphasizes that such questions are relevant and deserving of attention from undergraduate BME course organizers *prior* to their idealization and implementation. For instance, Figure 2 presents the Undergraduate Outcomes from Northwestern University (USA) in BME from 1991 to 2002. The results are self explanatory.

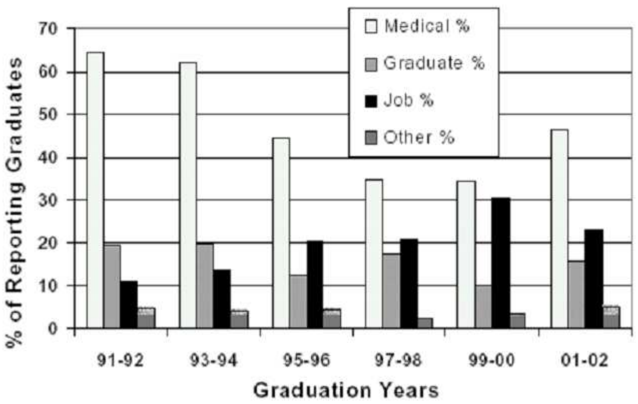

Figure 2. Undergraduate Outcomes from Northwestern University (USA) in BME

STRUCTURE OF UNDERGRADUATE BME PROGRAM

It is very hard to standardize the structure of an undergraduate BME course, since it depends essentially on regional characteristics and the professional needs of local companies and health care facilities surrounding the Faculty. Nevertheless, a central core is unavoidable. The curricular structure of American Faculties which have had success in such courses, such as MIT[6-9], Stanford [10-11] and John Hopkins [12-13] can be used as a reference. The John Hopkins curriculum, for example, has a peculiar structure, when considered under the light of a central core. The Department of Biomedical Engineering in The Whitaker Institute at Johns Hopkins has a new curriculum because the Faculty have defined a set of "core knowledge" that every graduate of its undergraduate program should possess, organizing choices of advanced engineering courses around biomedical engineering focus rather than traditional engineering disciplines [12-13]. A summary of the 126 credits needed for BS in BME contains: Basic Sciences (46 credits, including 24 credits in Math, 10 credits in Physics and 12 credits in Chemistry), Humanities (18 credits), BME Core (29 credits), Advanced Engineering (27 credits, including 9 credits of BME electives, 12 credits of Advanced Engineering Emphasis Sequence and 6 credits of Focus Area Core), Modern Biology (3 credits) and Computing (3 credits). Mathematics (24 credits) can include Calculus, Linear Algebra, Differential Equation Theory, Probability and Statistics. The BME Core can include Molecular Biology and Biochemistry, Biological Models and Simulation, Biological Systems and Control (related to mathematical analysis of linear and non-linear systems), Thermodynamics and Statistical Physics, Engineering Analysis of Biological Systems from Molecules to Organs (including cells and cardiovascular systems, neural systems, genes to organs considering signal transduction, genetic circuits, bioinformatics, among others. Advanced Engineering can include at least 12 credits of Advanced Engineering Emphasis Sequence and at least 9 credits of Advanced BME Electives Appropriate to Student Interest The 6 other credits to complete the 27 credits needed in Advanced Engineering have to be selected in the following BME Focus Areas:

1. Biological Systems Engineering, including cardiovascular systems, systems in neuroscience, molecular/cellular systems, musculo-skeletal biomechanics
2. Computational Biology, including computational modeling, bioinformatics, imaging science, robotics
3. Sensors, Microsystems and Instrumentation, including neuroengineering, micro-devices, sensors, instrumentation , robotics
4. Cell/Tissue Engineering and Biomaterials, including tissue engineering, cell engineering, biomaterials, drug delivery

According to The Department of Biomedical Engineering in The Whitaker Institute at Johns Hopkins, building on the foundation of this core curriculum, each student is required to take a cohesive sequence of advanced engineering courses appropriate to one of four Biomedical Engineering Focus Areas. The choice of Focus Area is based on student's experience with the Biomedical Engineering Core and answers to the following questions:

1. Biological Systems Engineering: Do you want to focus on understanding, at a fundamental level, how biological systems work?
2. Computational Biology: Do you want to focus on the use of mathematical theory or computers to solve complex biological and medical problems?
3. Sensors, Microsystems and Instrumentation: Do you want to build devices that facilitate research or clinical medicine?
4. Cell/Tissue Engineering and Biomaterials Do you want to create replacement cells, tissues and organs?

The undergraduate BME course of John Hopkins is only one example among many others, but they are relatively similar in the USA, considering regional characteristics and the professional needs of local companies and health care facilities surrounding the Faculty, as wrote before.

UNDERGRADUATE BME PROGRAM ACCREDITING AND FORMALIZATION OF THE BIOMEDICAL ENGINEER PROFESSION

It is very important to have the undergraduate BME course evaluated and accredited by an independent and capacitated third party institution. The USA have the Accreditation Board of Engineering and Technology (ABET), which houses an Engineering Accreditation Commission for each specialization in Engineering, including BME programs evaluations [14]. A similar institution should be available in each country so individual characteristics can be respected. In Brazil such endeavor will probably be entrusted to the Culture and Education Ministry. The evaluation, or re-accreditation, should be repeated periodically and include the results of an analysis of undergraduate outcomes like that one presented in Figure 2.

In many countries accrediting the undergraduate course is enough to allow new Engineers to work in their field of specialty in any region of the state or country. This is not true in several other countries, however, which means one of the problems to be addressed by Faculties when creating an undergraduate course in Biomedical Engineering is the formalization of the Biomedical Engineer profession, so that new graduates can work on their field. Technical and scientific communities, businesses and local health care managers should help in the process. Normally the formalization or the license to work in the field is supplied by the Engineering Council. In Brazil an authorization is mandatory and should be given by the Architecture and Engineering Council (CREA, from Portuguese), which has unofficially informed this author (during his Presidency of the Biomedical Engineering Brazilian Society) that such formalization and licensing would be possible but not simple or quick. It was suggested as an easier route to include Biomedical Engineering as a specialization or application in Electrical Engineering. Brazil currently recognizes the specializations in Microelectronics, Electronic Systems, Control Systems, Telecommunications and Power and Automation Engineering as pertaining to Electrical Engineering.

DIVULGING THE CARRIER IN BIOMEDICAL ENGINEERING

After accrediting the undergraduate Biomedical Engineering course, those responsible for its idealization and implementation should start by checking market conditions and preparing a folder explaining the specifics and the scope of a carrier in Biomedical Engineering, highlighting the applications for each of the four sub-areas described before. For example, the Engineering in Medicine and Biology Society (EMBS) from IEE has published an excellent material in 2003 [15] concerning the following topics:

Is biomedical engineering right for you?
What do biomedical engineers do?
How do biomedical engineers differ from other biomedical engineers?
How much education does a biomedical engineer require?
How can a high school education prepare me for studies in biomedical engineering?
What type of university courses will prepare me to become a biomedical engineer?
What kind of practical experience can I expect to gain while training to be a biomedical engineer?
What are some of the key areas of biomedical engineering?
Where do I get more information about biomedical engineering programs?

A similar orientation material should be prepared and distributed by the Faculty to interested prospective students for an undergraduate BME course before their enrollment.

CONCLUSION

Undergraduate Biomedical Engineering Courses seem to be very necessary in emerging countries, and even in those less developed, but it is crucial that their organizers and university managers be well aware of related education, technical and social needs. Because of Biomedical Engineering's high level of specificity it is mandatory to continuously evaluate the market needs and the undergraduate outcomes - such as those presented in Figure 2 from Northwestern University (USA) - in order to adapt, modify, improve and update the curricular structure so that real regional needs are taken into consideration.

A critical and comparative analysis about the convenience, the feasibility and the prospects of Biomedical Engineering as an undergraduate course, with special emphasis on Brazilian needs and conditions leads to the conclusion that Biomedical Engineering courses may be convenient and feasible in many countries, or even in specific regions, and are consolidated in developed countries, the USA being the best and most advanced example. And they are improving and creating: The new Biological Engineering SB degree was launched in Massachusetts Institute of Technology in the 2005-2006 Academic Year. The MIT News published that MIT was declaring a Major and the class of 2008 was about to change the world of biology[16].

Nonetheless, some care must be taken when defining curricular structures for courses because of the different needs that different markets present to Biomedical Engineers. An alternative career which would be simpler to formalize and which offers a more stable demand for professionals would be that of Clinical Engineer. Such profession is considered the most likely to be created in Brazil, tailoring professionals to the needs of health care facilities, specially hospitals and medical equipment manufacturers. It is evident, however, that all conclusions and decisions depend fundamentally on socio-economic conditions (mainly economic growth) of the country or region in which an undergraduate Biomedical Engineering course is to be implemented.

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Congress, held in October, 2006 in the city of São Pedro, São Paulo state, Brazil [5].

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