Biomedical engineering undergraduate education in Latin America

R Allende\(^1\), D Morales\(^1\), G Avendano\(^1\) and S Chabert\(^1*\)

\(^1\) Biomedical Engineering Department, Universidad de Valparaiso, 13 Norte 766, Vina del Mar, Chile

E-mail: steren.chabert@uv.cl

Abstract. As in other parts of the World, in recent times there has been an increasing interest on Biomedical Engineering (BME) in Latin America (LA). This interest grows from the need for a larger number of such specialists, originated in a spreading use of health technologies. Indeed, at many universities, biomedical engineering departments have been created, which also brought along discussions on strategies to achieve the best education possible for both undergraduate and graduate programs. In these settings, different positions were taken as regards which subject to emphasize. In such a context, this work aimed to make a survey on the “state-of-the-art” of undergraduate BME education in LA, and to analyze the observed differences. Broadly speaking, similar education profiles are perceived in the entire continent, with main emphasis on electronics and bioinstrumentation, biology and informatics respectively. Much less relevance is given to biomechanics and biomaterials. This tendency is similar in Departments with many decades of experience or in newly opened ones.

1. Introduction
Biomedical Engineering (BME) is a multidisciplinary field that integrates various sciences, such as physics, chemistry, biology, mathematics, electronics and informatics, with the aim at developing technology innovations in health-related areas, at improving prevention, diagnostic and pathologies treatments and, thus, at improving the life quality of people [1].

In Latin America (LA), the first academic undergraduate programs were established in the 70s in Mexico (UAM) and in Colombia, and later in Argentina (UNER) in 1985. At the same time, various graduate programs were created in Brazil, Venezuela, Colombia, Peru, Uruguay and Cuba [2]. Recently, in the Latin-American continent, the number of Biomedical Engineering undergraduate and graduate programs has increased by as much as 10% per year. Hence, the number of Biomedical Engineers in the continent augmented as well [2]. This tendency was accompanied by a raising number of companies developing and supplying biomedical technologies. At present, for instance, 700 000 medical services can be found in the continent, and 15 000 suppliers [2].

The participation of Biomedical Engineers in Health Services or related areas is an unavoidable reality. The need is on engineers having competence not only in electronics and maintenance but also with knowledge on biology and physiology. The latter is fundamental, for two main reasons: when a new device or piece of equipment is being designed, including greater reliability and safety for both...
the patient and the operating technician; and when this professional interacts with physicians and technicians, to be capable of understanding their viewpoints. On such accounts, Biomedical Engineers are characterized as having even a wider knowledge panorama than other traditional-career Engineers. Thus, they shall be prepared with knowledge ranging from Biology to Electronics, from Physics to Medical Praxis and Norms, Legal Responsibility and other disciplines.

The purpose of this study was to analyze the actual state of undergraduate Biomedical Engineering education in the Latin American continent. Many times, discussions have aroused on how to reach an adequate balance among all the essential knowledge to fit into undergraduate programs. A summary is given here on the main elections made at various Universities of the continent, within countries with relatively similar context, that is, that of being Latin-American. The second purpose of this work was to study the possible differences on education among countries with long experience in BME education and countries with very few generations of BM Engineers working in their field. One hypothesis is that countries that already have graduated many BM Engineers may also have begun to develop more specialized engineers.

Information was obtained from course catalogues of universities having BME undergraduate programs. The information used is that one made public and of free access, mainly through web pages.

2. Material and Methods
In order to compare undergraduate programs within the Latin American continent, information was retrieved from course catalogues offered by universities with BME undergraduate programs, through their web page, trying to search the most updated data as exhaustively as possible.

Six different groups of courses were created to synthesize each course catalogue. Groups were: Informatics, Electronics and Bioinstrumentation, Biomechanics and Biomaterials, Clinical Engineering and Management, Biological Sciences, and Biomathematics, according to the classification proposed by Rodriguez for graduate programs analysis [2]. Basic engineering education and basic sciences were not taken into account, such as Mathematics or Physics. It was used neither the number of weekly class hours, nor the credits offered per course, because this information was not always present or calculated in an equal way among the different institutions.

In order to evaluate some potential difference in education between countries offering undergraduate BME programs for many years, and countries where these programs have been opened recently, two groups containing four academic programs were constituted based on the order of program opening year. Namely:

Group A: programs opened between 1970 and 1980: Universidad de Antioquia (Colombia), Universidad Autónoma de Occidente (Colombia), Universidad Manuel Beltran (Colombia), Universidad de Santiago de Cali (Colombia).

Group B: programs opened between 2000 and 2005: Universidad de Valparaíso (Chile), Universidad de Concepción (Chile), Universidad del Valle (Bolivia), Universidad Latina de Panamá (Panamá).

Results were analyzed using visualization of course average in each of the six predefined categories, using Work Position Analysis WPA [2]. This method consists in creating an axis for each of the predefined categories, and relating profile for a specific group. Tendency of a specific group towards a category is therefore visualized easily.

3. Results
Number of countries and number of Universities that offer undergraduate Biomedical Engineering education are given in table 1. Taking into account the total number of courses, basic sciences and BME specifics, an average of 50 classes are given for undergraduate programs, in 9 out of the 23 countries of Latin America.
Table 1. Number of countries and total number of universities in L.A. with Biomedical Engineering programs

|                          |                |
|--------------------------|----------------|
| No. of Countries in L.A  | 23             |
| No. of Countries that impart BE undergraduate education | 9              |
| No. of Universities that impart Biomedical Engineering | 50             |
| No. of courses per university | 30            |

From the analysis of BME specific courses (excluding basic sciences) show in all catalogues surveyed, the following results can be inferred: the strongest emphasis is found on Electronics and Bioinstrumentation, with a high standard deviation, whereas the weakest category is Biomathematics and Biomechanics, as detailed in table 2. Following Electronics, the most privileged areas are Biological Sciences and Informatics.

Table 2. Number of courses imparted as per classification of BME specific courses.

| Classification                                 | Courses |
|------------------------------------------------|---------|
| Informatics                                    | 4.4 ± 1.8 |
| Electronics and Bioinstrumentation             | 9.4 ± 3.8 |
| Biomechanics and Biomaterials                  | 2.4 ± 1.8 |
| Clinical Engineering and Management            | 3.1 ± 1.4 |
| Biological Sciences                            | 5.5 ± 2.8 |
| Biomathematics                                 | 1.8 ± 1.4 |

The panorama given by the WPA, in figure 1, confirms the weight of Electronics and Bioinformatics in both groups of “recent” and “experienced” programs. Both groups present the same tendency expressed in table 2. Programs with most experience show more equilibrated profile between the different areas, with exception of Biomathematics. Most recent programs present an even heavier weight towards Electronics, and less development in Clinical Engineering and Biomechanics. In each group, standard deviations oscillate between 1 and 2, except for Biological Sciences and Electronics.
4. Discussion
This study aims at performing basic quantitative comparisons of the main tendencies existing in undergraduate programs of Biomedical Engineering in Latin America. BME trajectory in LA is close to 40-year old. Undergraduate education has significantly grown in the last 20 years, when considering the number of Universities offering this kind of program: up to date, 9 out of 23 countries are forming Biomedical Engineers. These figures represent the necessity of bringing up professionals with adequate knowledge and competence to perform according to the context of each country.

With respect to the main tendency in the entire continent, education is mainly based on Electronics and Bioinstrumentation, leaving aside Biomechanics and Biomaterials (see table 2). This tendency is found in most of the universities surveyed, probably to form professionals dedicated to installation and maintenance of medical devices, as well as to improve and create new designs for said devices. Nevertheless, a small number of universities actually present some difference, such as at Universidad de Entre Rios UNER (Argentina) or Universidad Favaloro (Argentina), where the distribution of courses among the six areas defined here is more homogeneous.

Education oriented towards Clinical Engineering is of paramount importance because, with this, the future Engineer acquires new tools to support hospital design, viewing it from an optimal management of medical technology or, for instance, from safety viewpoints, and for technology acquisition management (maintenance of all forms, preventive, corrective, predictive), etc. [3]. In most of the programs analyzed here, however, Clinical Engineering education is not as developed as other areas,
in spite of being an area of lower cost to implement, though of greater need out in the field. This could be explained by a growing need for human resources, or the persistence of strong barriers that impede a real connection with health centers where to obtain some practical experience. This could be even truer for recently opened programs.

Other deficiency observed in courses catalogues is related to Safety in the Hospital, rather by showing more news, studies or investigations about this topic than dedicated classes. This observation must be taken with caution, because only course titles were analyzed, and not the program (syllabus) of each subject.

As regards Biological Sciences courses, most importance is given to Molecular and Cell Engineering, while the universities offer very little formation on Anatomy. Some BM Engineers justify the need for including Anatomy in the course catalogue, as this subject brings fundamental knowledge to any BM Engineer, specially to increase his(her) medical lexicon with which enable him or her the best level of competence when interacting with physicians. Yet, another viewpoint considers that extensive Anatomy classes do not bring further benefit to the student, specially when taking into account the relatively short amount of time along the entire education program, and to the fact that Anatomy is not as essential to understanding the fine mechanisms of life, as opposed to cell and molecular biology.

Biomathematics was considered a full area in itself due to its importance in forming the future graduate students: a Biomedical Engineer must be able to relate mathematics with biology. Yet, this point is not relevant for undergraduate programs in LA. Probably, this is the reason why universities offer so few courses in this field (see table 2). Teaching of mathematics and physics covers the same areas as those given in “conventional engineering” programs, where the student solves problems in class and analyzes situations that differ much from those arising in hospital settings, or in biomedical device manufacturing companies.

Since the early times of Biomedical Engineering as an undergraduate academic program, a hot debate has arisen on whether to forming generalist Engineers or specialist professionals. Specialization may prove necessary in developed countries, where a BM Engineer can work within a predetermined family of medical devices. Nevertheless, by being specialized in some area of interest, the professional loses some global knowledge in other important areas. In particular, in Latin American countries a BM Engineer must be proficient enough as to adapt himself and solve very different problems, in health centers as well as in medical device companies. The best condition arises when an extensive education is given so that it covers a wide range of knowledge with which the engineer can effectively face up whichever situation may come. This mainly occurs in undergraduate programs, where the future engineer studies fundamental topics along the 5 or 6 years of education. If he(she) wishes to go on, further specialization is given along with graduate studies, thus increasing his(her) “domain of competence”, as represented in figure 2.

The same global tendency is observed in newly created BME departments or departments opened earlier, the latter presenting more homogeneous profile between all studied areas and, therefore, creating rather generalist engineers (see figure 1). On the other hand, newly created departments are strongly oriented toward educating Bioinstrumentation-specialist engineers. This is probably due to the creation of the BME department itself responding to the necessity detected in health centers to assist the specific problems linked to complex equipment. It is probable that most of the Biomedical Engineering education programs are developed by electronic-related professionals, to whom clinical engineers and mechanical engineers later get associated. These are only tendencies; the small number of samples and the variability between the profile for each department make the conclusion to be taken with caution.

To modulate this analysis, it must be noted that each course catalogue must fit the local study plan, and to the country context surrounding the university. Besides, some topics coverage can be explained not only by the detected external needs but also by the existence and availability of professors nearby.
It is interesting to read the results of this analysis from the Madrid debate point of view, in 2002 [4], where specialists concluded that the main points to take into account are:

1. Bioelectricity and Biomagnetism
2. Electromedicine and Bioinstrumentation
3. Signal and Image Processing
4. Biomaterials and Biomechanics
5. Biomathematics, Modeling and Simulation
6. Bioinformatics and Communication Theory
7. Clinical Engineering and Hospital Safety
8. Design and Equipment Construction
9. Telemedicine and Telesurgery

In all Latin American universities, all seven first areas are present. Equipment Design and Telemedicine are not promoted in the undergraduate student, probably due to the lack of time to teach such state-of-the-art techniques. In most universities these last two points are present as elective courses, for instance in the Universidad Antonio Narino (Colombia). Even though courses as Bioelectricity, Electromedicine, or Bioinstrumentation are present in most catalogues, there is a lack in Biomechanics and Biomaterials. It can be hypothesized that this is due either to the complexity to implement this kind of classes, in particular regarding access to laboratory or didactic equipment, to obtain practical knowledge; or to the low level of need for biomechanical engineers perceived in the Latin American labor market.
These deficiencies are also reflected in a survey made by the Centro de Conocimientos en Ingeniería Biomédica CCIB (Center for Knowledge in Biomedical Engineering) on Latin-American professionals [2]. Among the most important questions raised from this survey were those related to needed requirements to improve professional fulfillment, more specifically general knowledge of medical devices, biology and human physiology, management, as well as on lists of equipment and device suppliers, as well as maintenance protocols.

5. Conclusion
A study of undergraduate education in Biomedical Engineering in Latin America was here undertaken aiming at knowing which are the privileged areas being developed in the continent. A basic quantitative comparison of the courses offered was made to try to determine the professional competences of local BM Engineers, based on courses catalogues available from public university websites.

Broadly speaking, a similar profile can be seen all over the continent, with greater emphasis put on electronics, biology and informatics respectively, while biomechanics and biomathematics are much less developed. This tendency is similar in both newly created university departments and in departments with longer experience (30 – 40 years).

Biomedical Engineering came to light mainly from the need to assist the ever increasing and more complex problems related to medical equipment of a modern health center. This is probably the same necessity in Latin America that made emerge strong education programs in Bioinstrumentation in various countries, well complemented by Biology teaching.

The presence of a professional with solid knowledge of Clinical Engineering in health centers is a fundamental factor, especially as regards overall hospital safety. It is interesting to note that, in spite of the importance of such areas, few universities promote strongly the formation of clinical engineers in Latin America.

The next challenge may stem from trying to unify the effort to create professionals with sufficient tools and knowledge to apply them in the health-related sector, or –instead- trying to generate specialized Departments in specific regions of Latin America. On top of this, the arising question is related to whether, at some point, space shall be created to develop specialization areas, such as Biomaterials or Cell and Tissue Engineering, while the increase of medical progress in Genetics, Molecular Imaging, and other disciplines gain prevalence in Latin America as well.

References
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