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Managing new directions for a 38 year old undergraduate BME program

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Abstract—**The Biomedical Engineering curricula in general must reflect the state of the art in the technology related to medicine and health care, as students who graduate from these programs are directly related to the well-being of the patients, either through new devices and technologies being invented or through the application of their technical knowledge in the service industry. At present, there are more than 25 BME undergraduate programs in Mexico. Most of them are oriented towards the instrumentation and clinical engineering branches of the field, while a few others have strong components in signal analysis. The program at Universidad Autónoma Metropolitana (UAM) is one of the oldest and has been used as a reference by most other programs. Since UAM is one of the top three research universities in the country, it is well poised to incorporate its research directions into a more modern curriculum. This paper deals with the efforts that have been carried out in order to minimize the excessive influence of the electrical engineering subjects in the BME undergraduate curriculum and the approaches to reach consensus-based decisions to explore new directions related to emerging disciplines in medical technology and health care. After analysis of the current state, a discussion on future directions is presented.**

I. Introduction

THE Biomedical Engineering (BME) undergraduate program at Universidad Autónoma Metropolitana (UAM) is almost 40 years old. Together with the BME program at Universidad Iberoamericana (UIA), they are the oldest programs in Latin America (both started in early 1974) and closely follow the first programs in the United States such as those of Duke (1972) and U. Penn (1973).

After all these years, the program still reflects the interests and academic background of the founding faculty, which was mostly in Electrical Engineering (EE). This and other factors explain the overwhelming interest in medical instrumentation (and later in clinical engineering) at the time.

In this new century, there are new and emerging subdisciplines intervening in the application of engineering and technology to health care and although the BME curriculum has been updated every three or four years, it is necessary to overhaul the program in order to rid it of the excessive influence of the original "founding faculty's" background and to structure the program according to the new emerging subdisciplines. Fortunately, the academic organization at UAM as a research university allows the incorporation of new research experiences into undergraduate teaching as all the faculty members are charged with teaching and research work. This paper presents the results of recent reorganizations of the BME curriculum together with an analysis of future directions that may be needed to be taken in order to reorient the program towards these new emerging subdisciplines.

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II. Background

To state the problem simply, the goal was to manage the transition from an EE-based BME program to one that emphasizes new technologies and directions in health care.

While BME programs in the US, Canada and Europe were initiated at the postgraduate level and were derived from the application of electronic instrumentation to biomedical measurement after World War II, in Mexico BME started with the expansion of higher education in the seventies and was due to the need to provide better health care technology management and maintenance in the expanding health care system. The original curriculum was influenced by several factors that are still important today such as:

- Background of the faculty (most were EEs with experience in hospital equipment maintenance).
- The historical context and policies regarding research and development (R&D).
- The state of the art in medical and electronics instrumentation.
- The strengths and weaknesses of the following generations of faculty members.

Initially, most if not all the professionals working in hospitals and in medical equipment maintenance were electrical and electronics engineers and some of the most experienced of these engineers were hired both at UAM and UIA as the first teachers in the BME undergraduate programs. In both institutions the only professors with graduate degrees and research experience were the program coordinators. The rest of the faculties were made up of people with engineering degrees and who were later encouraged to obtain their postgraduate diplomas.

The national R&D policies were oriented towards the strengthening of an internal market, that were supplemented by protectionist measures and the development of measures to minimize the "technological dependency" and import substitutions, so original research was practically non existent until the program's second decade. In view of all this, it is not surprising to find that the main emphasis of the first versions of the curriculum were medical instrumentation and clinical engineering.

The second generation of faculty members was made up mostly of BME graduates within the same university who had obtained an additional graduate degree (mostly Master's

degree in Science or Engineering) with an emphasis in signal analysis.

The influence of the second generation on the curriculum was to incorporate subjects from the Signal Processing field to the curriculum, without significantly trimming the existing series of required courses, so this entailed a growth in the number of credits required for graduation. This influence is still being felt in the latest version of the curriculum.

III. Problem Statement

At present, 35 years after the founding of the EE Department at UAM, there has been a growing separation between the research interests of the BME faculty (over 35 faculty, six research laboratories and a research center; the authors are members of this faculty) and the undergraduate BME curriculum. The faculty has been loath to make changes to the course structure and this made it difficult to include new subjects in emerging disciplines that are now being actively researched in laboratories at the university as in the case of biomaterials, tissue engineering and nanotechnology, among others. Although through these years there have been over 10 modifications to the structure, it was only recently that a methodology for change has been adopted that has resulted in a real advancement in the scope and depth of inclusion of new emerging research themes related to BME.

Some of the problems were related to the structure of the BME faculty. For example, there was a feeling of "ownership" of the structure and contents of the required courses and the resistance to change reflected the idea that all of the courses that were being offered were essential for the development of a competent biomedical engineer. Any change in the structure of required courses was deemed a "watering down" of the graduation requirements.

Figure 1 shows a simplified diagram of the curricular structure of the BME program in the early years (seventies and eighties). It shows the conventional organization of a common basic science trunk, an engineering trunk and then two branches covering the physiological subjects and several subjects in medical instrumentation. At the time resources were scarce, so there were no real electives: the program was rigid and prerequisites were strict. The engineering trunk was based on subjects that were common to the undergraduate degree in electronics engineering.

Qtr	1982									
1	Phys	Math		Chem						
2	Phys	Math		Chem						
3	Phys	Math		Chem						
4	CompProg	Math	Math	Circuits	AnalogElectr					
5	CompProg	Math		Circuits	AnalogElectr					
6		Math	Math	Circuits	AnalogElectr	Mechanics				
7		Math			AnalogElectr	Mechanics	Physiol			
8					DigitalElectr	Mechanics	Physiol	MedInstrum		
9					DigitalElectr		Physiol	MedInstrum	MedInstrum	
10					DigitalElectr	Mechanics	Physiol	MedInstrum		
11					DigitalElectr			MedInstrum		CapstoneProj
12					AnalogElectr			MedInstrum	MedInstrum	CapstoneProj

Figure 1. Curricular structure for the BME program in the early eighties. It can be seen that there are a significant number of EE required courses

Required courses in electronics were originally shared with the Electronics Engineering program, and thus, aditional resistance to change from these engineers meant that there was no possibility for a change in these subjects.

Semiconductor Physics was a required course for BMEs until the early 90s. There were over one year's worth of courses (3 trimesters each) in electrical circuits, analog electronics and digital electronics before the student was allowed to take subjects that were directly related to BME. This is the main structural restriction that has resulted in the difficulties to reorganize and renew the BME curriculum.

Figure 2 shows the simplified structure when the curriculum was heavily influenced by the second generation of professors (at least six new professors with this background) who were Signal Processing experts.

Qtr	1996									
1	Phys	Math		Chem						
2	Phys	Math		Chem						
3	Phys	Math		Chem						
4	CompProg	Math	Math	Circuits		Hosp/Clin				
5	CompProg	Math		Circuits	AnalogElectr					
6		Math	Math	Circuits	AnalogElectr					
7	CompProg	Math	Math		AnalogElectr	Hosp/Clin				
8	CompProg				DigitalElectr	Hosp/Clin	Physiol	MedInstrum		
9					DigitalElectr		Physiol	MedInstrum	MedInstrum	
10					DigitalElectr		Physiol	MedInstrum		
11				AnalogElect	DigitalElectr		Physiol	MedInstrum	MedInstrum	CapstoneProj
12				Sig&Syst				MedInstrum		CapstoneProj

Figure 2. Curricular structure in the mid nineties. Note the increase in required programming subjects and the inclusion of Clinical Engineering subjects

These previously mentioned characteristics of the early curricular structure show how significant the common trunk structures in basic sciences and electrical engineering have been. Although they served well years ago, they are now a hindrance to the incorporation of new subjects and directions in the field of BME. It is no longer necessary for all graduates in this discipline to be experts in electronic instrumentation. There are several new and exciting fields related to the use of science and technology where biomedical engineers can contribute to and these opportunities should be emphasized in future curricular design efforts. The main problem to update the curriculum was to manage the transition from an EE-based program by firstly, shortening the chains of prerequisites in several courses and to add a set of different electives that would point to new directions.

IV. Results of Recent Work

At the end of the nineties and the beginning of the 21st century the BME faculty at UAM had been recognized as being the most influential in Latin America: it had 6 research laboratories, graduate and undergraduate programs that were highly regarded by accreditation agencies and had been influential in the establishment of several research groups in Latin America. During one of those accreditation evaluations it was established that one flaw in the BME undergraduate program was that there very few electives in general and that it was essential to include electives in the humanities in order to maintain accreditation. This proved to be a good opportunity to (in addition to these subjects in the humanities) include several subjects that were more closely related to the researchers' fields of interest. For example: image processing, advanced computing, stochastic processes and magnetic resonance imaging, among others. It was always a stated goal at the University that, being research-oriented, it should strive to incorporate research results and approaches into undergraduate teaching, so the need to mod-

ify the curricular structure in order to incorporate the humanities' credits, together with the desire to teach new subjects pushed the faculty to study different solutions. Ironically, one of the strengths of the University, which is the largely democratic processes for the approval and authorization of changes through divisional and academic councils complicated the process of consensus-based change.

The faculty was organized into sub-committees that evaluated the need for curricular modifications in different subfields such as electronics, physiology, signal processing, computing and instrumentation. It was during these evaluations that it became evident that every expert wanted to "defend" his field of interest and wanted it to be considered as essential for the curriculum. For example, electronics professors wanted to require all of the students to take a course on power electronics. In order to avoid eliminating some of the contested subjects, it was proposed to focus on the number of credits and on the structure of the curriculum and to then propose a path where through the chioce of electives, the students could become profficient in the subjects that the different sub-committees deemed necessary.

This work finally allowed the transition to a new structure where the "nuclear " subjects are few, and are surrounded by a "cloud" of electives. Figure 3 shows a simplified structure of the current curriculum at UAM. It is still essentially a trunk-based organization, but with a very wide bushy structure at the top where there is a great diversity of subjects that can be selected mostly in the third and fourth years. It is important to notice that although it was possible to reduce the number of electronics and required instrumentation courses, the faculty's influence is still evident as the curriculum has changed from 12 required subjects in circuits and electronics in 1982, to 5 courses in electronics plus three in signal and systems in 2010.

Qtr	2006-2010									
1	Phys	Math						IntroBME		
2	Phys	Math		Chem						
3	Phys	Math		Chem						
4	CompProg	Math	Math	Circuits						
5		Math		Sig&Syst	AnalogElectr		Physiol			
6			Math	Sig&Syst	AnalogElectr		Physiol			
7		ElectBME		D&A Filters	DigitalElectr		Physiol			
8		ElectBME			DigitalElectr	ElectHuman		MedInstrum		
9		ElectBME				ElectHuman		MedInstrum	MedInstrum	
10		ElectBME				ElectHuman				CapstoneProj
11		ElectBME				ElectHuman				CapstoneProj
12		ElectBME				ElectHuman				CapstoneProj

Figure 3. Current BME Curriculum. There are many electives required for the humanities and for BME. Although the number of required courses in circuits and electronics have been reduced, there has been an inclusion of three signals & systems related subjects.

At present there are 28 available subjects in the field of BME plus a series of other electives that can be selected from the basic sciences and engineering division. The BME electives comprise 7 groups of subjects that can be taken together to form a sort of "minor", for example in imaging instrumentation, technology management, quantitative physiology, etc, or can be taken independently. The required subjects that had to be dropped in order to make place for the humanities now are part of the pool of electives, so no one professor or research group feels that "their" subjects are not represented. Nanotechnology, Biomaterials, and Quantitative physiology are examples of these new subjects being taught [6,7]. Figure 4 shows the current balance of numbers of groups of subjects being offered. Figure 5 shows the BME group of electives. The original group of electives now incorporates a series of previously required courses. The new courses in this cloud structure reflect the strengths of the research labs at the institution and a series of new proposed subjects is also shown.

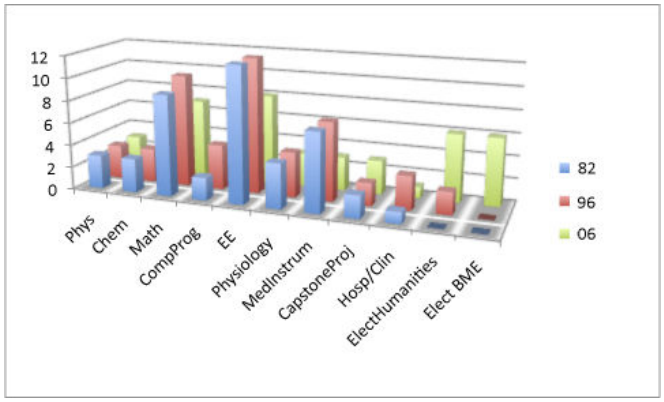

Figure 4. Course distribution by groups of subjects. It can be seen that the groups of EE subjects has dropped by one third, while an important group of electives now replaces most of the required subjects in instrumentation.

Traditional (prevRequired)	New (2010-2012)	Future (from UAM-C)
Control		
Electronic Interfaces		
Programmable interfaces		
Clin. Lab. Instr.		
Intensive care instr.	MRI	fMRI
Med. Imaging	Image Processing	Ultrasound in Medicine
ClinEngrProg	Quality Analysis	
Hosp.Prog.	Med. Tech. Mgt.	
HospPractice	Health economics	
Physiopathology	Quantitative Physiol	Molecular Physiology
	Innovation&Entrepren	Molecular Bioinformatics
	Cellular Electrophysiol	Proteomics
Computing systems	Comput Methods BME	
Stochastic processes	Comput Visualization	
Selected Topics	Nanotechnology	
	Biomaterials	

Figure 5. Set of elective courses. Previously required courses that are now electives are shown in red; the current supplementary group of electives is blue and the proposed electives for the future are shown in green for internal courses and orange for courses at UAM's campus in Cuajimalpa.

V. Discussion

During the last 38 years BME academic program has been transformed from a rigid field-oriented curricula to one that is flexible and student-oriented. This last approach has positive aspects as well as limitations.

The advantages of this approach are:

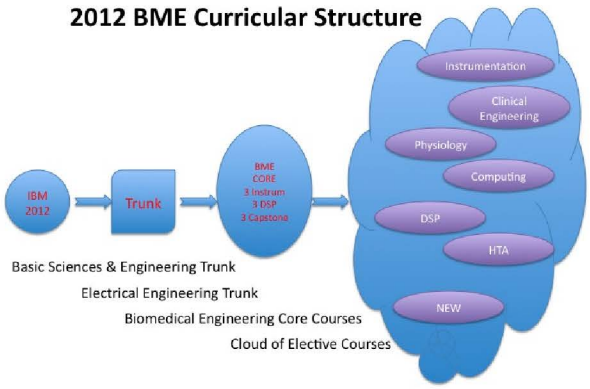

Figure 6. Schematic representation of current "cloudlike" curriculum with groups of electives

- The workload from traditional subjects, or "baggage" is reduced. While there are still several subjects where its relevance is debatable, it is no longer required to take all of the subjects in medical instrumentation that can be or have been offered (there used to be 5 required plus two elective subjects in medical instrumentation).
- Curriculum is now student-centered: the student has a much wider group of elective subjects to choose from, and can construct his own "tailor made minor" according to his specific research or capstone project needs.
- The diverse subjects that can be offered reflect the researchers' genuine interests.
- Modifications to the curriculum are fast and easy. Electives can be proposed and approved in a timely fashion.
- It is an "evolving" curriculum. Subjects are offered on an annual basis, but those that have no registered students can be dropped after they prove to be unpopular or irrelevant after a certain amount of time.

Some disadvantages are:

- The lack of structure allows the student to choose freely from different subjects and this could lead in some instances to a "minimal effort" approach in some cases.
- It requires more effort in planning for the program coordinators.
- It also requires an academic staff commitment on constantly improving the quality of subjects they teach, which is something that can't always be achieved.
- The contents, modes of conduction and of evaluation of the teaching process have to evolve over time, and this is not always well understood either by the teacher or the student.

However, an important consideration in this reform is that the structure allows the development of new curricular directions without seeming to edge out traditional approaches to BME, so while the "core" curriculum was centered on medical instrumentation, these subjects have been reduced from 6-7 to three. The remaining instrumentation courses are:

- Biomedical Systems Measurements
- Measurement of Bioelectric Phenomena
- Measurement of Flow, Pressure and Volume (FPV),

and it can be foreseen that at least the FPV course can be moved to the group of elective subjects or al least to be considered under a different point of view, for example as an integrator course, incorporating lab work from different subjects.

This approach has proven to be more acceptable to a traditionally-minded segment of the faculty. Since the conventional structure was allowed to be preserved, it was easier to approve changes in the approach to electives. This might be the most important consideration for the possibility of the development of an alternative curriculum (at UAM, most changes are slow and difficult, since traditionally, such changes are consensus-based). If the student is determined to follow the traditional instrumentation path, the remaining subjects (such as clinical laboratory instrumentation and intensive care instrumentation) can be taken as electives.

Although this structure has allowed the curriculum to be diversified, it is still very much influenced by the subjects from the EE disciplines. The legacy curriculum calls for two required courses in Signals and Systems plus another required course in Analog and Digital Filtering. Nowadays, it has become increasingly hard to justify the need for all of the students to have such comprehensive competencies in the field of EE and there are still almost a year's worth of EE courses.

In practice, the evolution or orientation of the different branches of BME that are being offered through electives reflects the tendencies that are found in the professional field. For example, series of courses dedicated to the management of medical technology: Health Economics, Quality Analysis in BME, Innovation and Entrepreneurship and Medical Technology Management are being preferred over traditional Clinical Engineering courses such as Clinical Engineering Programs [5].

VI. Future Directions for the BME Program

Although the structure just presented is a significant improvement on the legacy program, it must still be perfected. The problem of long chains of prerequisites for different subjects is still a bottleneck for students wanting to progress rapidly through the curriculum; and the trunk structures do not allow the students to take courses that are close to their interests until after two years of study. The structure of the curriculum of the undergraduate program in BME has not kept up with the development of disciplines such as nanotechnology, cellular engineering and bioinformatics, which are very promising employment opportunities in the emerging biologically based engineering [1, 2, 3].

Thirty-eight years ago, the original BME curriculum at UAM was up to date and reflected the adequate emphasis for the needs of the health care system and biomedical industry: circumstances required that graduating BMEs needed to be competent in subjects that were more technical rather than professionally oriented. Nowadays we have the opportunity to educate engineers that can contribute to the BME discipline in the fields of development and innovation.

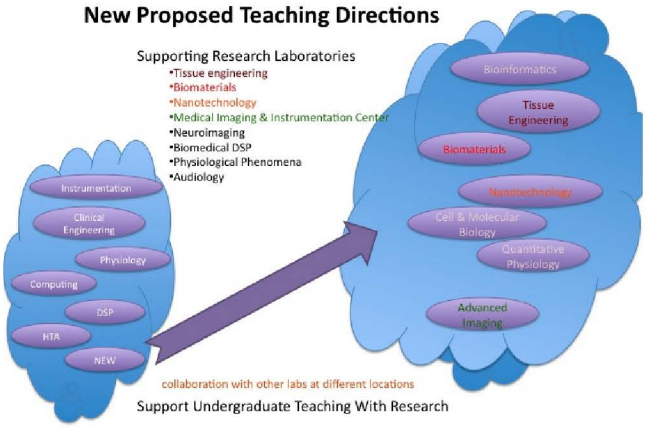

Figure 7 Schematic representation of the proposed curricular change emphasising research-oriented elective subjects.

It can be said that at the time it could be considered to be a successful program: over 1000 students have graduated from the University and over half of all the Clinical Engineering Department directors in Mexican hospitals are UAM graduates. The Biomedical Engineering programs have been so popular that there are now 25 institutions offer BME programs in Mexico [4], and most of those offer the same "classical" branches in medical instrumentation and clinical engineering, while a few others are strong in signal analysis and pattern recognition in BME. This fact presents our University with an opportunity to reorient the emphasis of the BME program since it is evident that all the other institutions are or will be targeting the formation of human resources in a discipline where the UAM has already made its mark.

Even though the old program was sucessful, employment expectations have tended in recent years towards equipment sales and servicing which are close to being jobs for technicians. Better jobs are available at an emerging group of pharmaceutical industries and research facilities in industry and academia, but these jobs frequently require a graduate degree. In this case students with a background in these new disciplines are better prepared to undertake their studies at this level.

The strengths of the BME faculty at UAM allow a change of emphasis in the undergraduate program. While at present, a few emerging disciplines are represented in the BME curriculum, in the near future it will be possible to incorporate a complete series of subjects in the fields of the nanobiosciences, bioinformatics, tissue engineering and biomaterials will be incorporated. These will result from the current collaborations among research groups at the institution. At the Basic Sciences and Engineering Divisions there are several laboratories that are now participating in the Graduate Program of BME (nanotechnology and biomaterials) and it is not unforeseeable to incorporate both common research and a series of electives from different campuses and programs at our University.

This change of emphasis in competencies from service-oriented to innovation and research and development will allow the BME program at UAM to remain at the top of the academic options in Mexico and Latin America.

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