33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Promoting Harmonization of BME Education in Europe: The CRH-BME Tempus Project

Nicolas Pallikarakis, *Member, IEEE,* Zhivko Bliznakov, Damijan Miklavcic, Tomaz Jarm, Ratko Magjarevic, *Member, IEEE*, Igor Lackovic, *Member, IEEE*, Leandro Pecchia, Rita Stagni, Akos Jobaggy, *Senior Member, IEEE,* Joseph Barbenel

***Abstract*—Biomedical Engineers should be prepared to adapt to existing or forecasted needs. There is a strong pressure on education, training and life long learning programs to continuously adapt their objectives in order to face new requirements and challenges. The main objective of the TEMPUS IV, CRH-BME project is to update existing curricula in the field of Biomedical Engineering (BME) in order to meet recent and future developments in the area, address new emerging inter-disciplinary domains that appear as a result of the R&D progress and respond to the BME job market demands. The first step is to extensively review the curricula in the BME education field.**

In this paper, a proposal for a generic curriculum in the BME education is presented, in order to meet recent and future developments and respond to the demands of the BME job market. Adoption of the core program structure will facilitate harmonization of studies as well as student and staff exchange across Europe, thus promoting the European Higher Education Area.

Manuscript received March 26, 2010. This work has been carried out within the framework of the CRH-BME project – Curricula Reformation and Harmonisation in the field of Biomedical Engineering, Joint Project within the TEMPUS IV program and 95% financed by the Commission of the European Communities.

N. Pallikarakis is with the University of Patras, School of Health Sciences, Department of Medical Physics, Biomedical Technology Unit, 26500, Rio, Patras, Greece. (e-mail: nipa@upatras.gr).

Z. Bliznakov is with the Institute of Biomedical Technology, 26500, Rio, Patras, Greece. (e-mail: jivko@inbit.gr).

D. Miklavcic is with the University of Ljubljana, Faculty of Electrical Engineering, Trzaska 25, 1000, Ljubljana. (e-mail: damijan.miklavcic@fe.uni-lj.si).

T. Jarm is with the University of Ljubljana, Faculty of Electrical Engineering, Trzaska 25, 1000, Ljubljana. (e-mail: tomaz.jarm@fe.uni-lj.si).

R. Magjarevic is with the University of Zagreb Faculty of Electrical Engineering and Computing, Unska 3, Zagreb, Croatia. (e-mail: ratko.magjarevic@fer.hr).

I. Lackovic is with the University of Zagreb Faculty of Electrical Engineering and Computing, Unska 3, Zagreb, Croatia (e-mail: igor.lackovic@fer.hr).

L. Pecchia is with the University of Naples - Federico II, Department of Biomedical, Electronic and Telecommunication Engineering, Via Claudio 21, 80128, Naples, Italy. (email: leandro.pecchia@unina.it).

R. Stagni is with the University of Bologna, Department of Electronics, Computer Science and Systems, Viale Risorgimento 2, 40136, Bologna, Italy. (e-mail: rita.stagni@unibo.it).

A. Jobbagy is with Budapest University of Technology and Economics, Department of Measurement and Information Systems, Magyar Tudosok krt. 2, 1117, Budapest, Hungary. (e-mail: jobbagy@mit.bme.hu).

J. Barbenel is with the University of Strathclyde, 204 George St, Glasgow, UK. (e-mail: j.c.barbenel@strath.ac.uk).

I. Introduction

In the European Union the political decision for the creation of The European Higher Education Area (EHEA), aims to lead to comparable degrees, based on two main cycles articulating higher education in undergraduate and graduate studies, with harmonized programs, thus facilitating student exchange. The establishment of the European Credit Transfer and Accumulation System (ECTS) [1] increased the flow of students and teaching staff between universities. However, although many countries have officially adopted the principles of Higher Education reform, they are very slowly implementing the necessary changes for harmonization. In the EHEA implementation, obstacles often arise from administration, lack of knowledge, or students' reactions, due to misunderstanding. The Biomedical Engineering (BME) field, belonging to the broader engineering area with traditionally five years of studies for graduation, has faced a strong opposition in its reformation.

Even though the term biomedical engineer includes professionals with very heterogeneous areas of specialization, their profiles nevertheless share common characteristics which define and make them unique among the engineers. There is no doubt that a biomedical engineer must be an engineer first and as such must possess a sound and relatively broad knowledge of fundamental engineering and physical science. Furthermore, unlike other engineers, he must be able to apply this knowledge to solve problems of medical and biological origin, which all require a multidisciplinary approach. Problems that biomedical engineers are expected to solve today vary tremendously and this diversification can only be expected to increase further on with new and rapidly emerging technologies and demands of the health sector. For this reason any BME study program must provide, in addition to a sound BME foundation, specialization elements within a narrow field of BME, which address current and future needs [2].

In this paper we present a proposal for a generic curriculum in the field of BME, in order to meet recent and future developments and respond to the demands of the BME job market. Adoption of the core program structure will facilitate harmonization of studies as well as student and staff exchange across Europe, thus promoting the European Higher Education Area.

II. Types of BME Study Programs

The results of a survey of 300 BME programs carried out as a part of the CRH-BME project [3] to evaluate the present status and future needs in BME education have shown clearly that 1st and 2nd cycle (MSc level) programs are the predominant form of BME education, (~30% BSc, ~50% MSc, ~20% PhD). This was not surprising since the profile of a biomedical engineer is that of an engineer cross-trained and specialized in biomedical application areas, and it the most straight-forward and logical pathway is therefore to recruit students of biomedical engineering from the pool of graduates of "classical" engineering disciplines (such as electrical and mechanical) or physical sciences.

The CRH-BME consortium developed proposals for generic programs for 1st and 2nd cycle degrees, as defined by the Bologna declaration; third cycle Doctoral programs were not considered because the core generic BME instructional material is delivered in 1st and 2nd cycle programs with the PhD being much more specialized. Biomedical Engineering is based on a sound knowledge of, and competence in Engineering, Physics and Mathematics, and of relevant Biological and Biomedical sciences. The structure of the proposed Biomedical Engineering programs is, therefore, hierarchical and progressive. Generic syllabuses are proposed for five generic types of biomedical engineering programs and are based on previous experience and information gathered about specific needs in different environments. The types of programs addressed here, are based on the EHEA guidelines and are as following:

Type 1: 1st cycle BME program (for employment).

Type 2: Integrated 1st and 2nd cycle BME program.

Type 3: Stand-alone 2nd cycle BME program with entry from 1st cycle BME program.

Type 4: Stand-alone 2nd cycle BME program with entry from 1st cycle engineering or physical sciences program.

Type 5: Stand-alone 2nd cycle BME program with entry from 1st cycle medical or biological program.

ECTS points allocated to the main identified topic categories are indicated in the following table. Figures should be taken as a guideline, but recognize that variations will occur because of the different expertise and facilities of course providers; however it is suggested that deviations of no more than 25% (or up to 10 ECTS) in the topic categories will be sufficient to face these differences.

The programs commence with education in Basic Engineering and Physical Sciences, and Basic Biological and Biomedical Sciences. The duration and content of this aspect of the programs depend on the prior knowledge and experience of the students undertaking each program. Those undertaking a First cycle program or an integrated First and Second cycle program are expected to have very limited knowledge in both Basic areas and the time (and ECTS) devoted to basic material should be considerable. Those entering Second cycle programs can be expected to have high level knowledge acquired during their First cycle degree and the duration of the Basic aspects of the program is correspondingly decreased and tailored to the nature of the students' prior knowledge e.g. whether it was an Engineering or Biologically based degree. There is also recognition of the non-technical competencies and skills needed to practice Biomedical Engineering in an academic, industrial or health care context. Effective communication, both written and verbal, is vital for effective team working which is central to much Biomedical Engineering activities. Additionally management skills are essential to obtain the best results from such team work. All students must be aware of the ethical context in carry out and publicize research as well as the specific ethical constraint on working within the medical area. These non-technical aspects may be delivered as stand-alone courses or could be integrated within the other program topics. All students will be expected to carry out research of significant depth to demonstrate their expertise in the application of ideas and techniques

TABLE I
Biomedical Engineering study programs and distribution of ECTS.

Degree / Program Topic category	Type 1	Type 2	Type 3	Type 4	Type 5
Basic Engineering and Physical Sciences	70	100	15	5	20
Engineering and Physical Sciences focused on BME applications	20	40	10	10	10
Basic Biological and Biomedical Sciences	15	25	5	20	5
Biological and Biomedical Sciences focused on BME applications	20	30	10	10	10
General introduction to BME and BME specialization	30	60	20	15	15
Generic skills Ethics (general, medical, research) Management Visits to / from companies or lectures / seminars from staff of relevant institutions	10	15	5	5	5
BME Research project for thesis	15	30	25	25	25
Minimum total ECTS	180	300	90	90	90

The sum of the minimum total ECTS of the 1st cycle BME for employment program (180) and of any of the stand alone 2nd cycle BME programs (90) is only 270. It means that either the 1st cycle or (more likely) the stand-alone 2nd cycle must provide at least additional 30 ECTS to fulfill the requirement of the minimum of 300 ECTS for the combination of both cycles. In most instances 60 ECTS are delivered in the academic year, which is structured as 2 semesters, but some second cycle BME degrees are delivered as calendar years of 90 ECTS.

The 1st cycle BME programs for employment (Type 1) are primarily intended to satisfy the growing needs of industry and the health care sector for immediately employable biomedical engineers, but it can of course also serve as an entry point for 2nd cycle BME or any other engineering programs. The stand-alone 2nd cycle BME programs with entry from 1st cycle non-BME engineering or physical sciences (Type 4) will probably remain the most common type of BME program. Strong foundations in basic engineering, mathematics and physics, but little or no previous exposure to university-level biological and medical topics can be expected from these students upon entry to such a program. The stand-alone 2nd cycle BME programs with entry from 1st cycle BME program (Type 3) are similar to Type 4 programs in the sense that graduates of both types can be expected to possess similar level of integrative expertise in both engineering and medical-oriented topics upon completion of their respective studies. But the starting point is different to some degree, which is compensated for mostly by different proportions of basic engineering and biomedical components in the respective programs. In fact, a program may be considered Type 3 and Type 4 simultaneously if it provides the so-called bridging courses to bring students of various engineering backgrounds to a common level. The integrated 1st and 2nd cycle BME programs (Type 2) were proposed as an alternative to Type 3 and Type 4 programs with added benefit that it can avoid the overlap in contents that may occur in practice between independent 1st and 2nd cycle programs. Type 2 program can therefore provide a little more breadth or depth of knowledge to the students within the same timeframe as a combination of independent 1st and 2nd cycle programs, or provide for more flexibility in terms of distribution of its contents over its entire 5-year duration (e.g. 5 years) than a combination of independent 1st and 2nd cycle programs.

The last category proposed is the Type 5 stand-alone 2nd cycle BME programs with entry from 1st cycle biological or biomedical program, medical or medical related degree. The survey carried out within the CRH – BME project has shown that there exists a need for Type 5 programs, even though such programs will remain relatively rare; the need is likely to grow, driven by the increasing technical complexity of some clinical areas and of biomedical laboratories, and by the needs of evidence – based practice. Students entering such a program will have had very limited previous exposure to engineering, mathematics and physical sciences. Upon completion of their previous studies these students will not have acquired the engineering breadth and depth of students of Type 2, 3 and 4 programs, but their comparatively better knowledge in biological sciences is a benefit in some specialized areas of activity where some BME knowledge is both useful and desirable. In addition the increased complexity and development of improved analytical equipment in biomedical laboratories creates a need for biologically or biomedically qualified staff with higher levels of BME related knowledge and skills.

The 10 topic categories appearing in the tale can be grouped into 5 major groups:

- Engineering and physical sciences
  (1) Basic engineering and physical sciences
  (2) Engineering and physical sciences focused on BME applications
- Biological and Medical sciences
  (3) Basic biological and medical sciences
  (4) Biomedical sciences focused on BME applications
- (5) General introduction to BME and BME specialization – compulsory or elective
- Transferrable skills
  (6) Generic skills (verbal and written communications)
  (7) Ethics (general, medical, research)
  (8) Management
  (9) Practical experience - visits to/from companies, clinics, industry or lectures/seminars by relevant staff
- (10) BME research project for the thesis

The engineering and biological contents of the 5 program types are specified as either basic or focused on BME applications (Applied). The basic categories include topics (or contents) that may be most efficiently presented to, and best absorbed by, the students if taught primarily in a traditional way with only limited direct links to BME applications, which can, however, be exploited to further motivate students. Basic topics are meant to provide the foundation on which the application-oriented topics can build. Basic engineering and physical sciences topic (category 1) provide knowledge of mathematics, physics, computer/programming and the principles common to most engineering disciplines (with emphasis on electrical, mechanical, and/or chemical engineering). Basic biological topics (category 3) introduce the students to topics such as cell biology, and basic anatomy and physiology (normal and pathological).

The BME focused applied engineering topics (category 2) expand on the physical and engineering principles necessary for understanding biomedical phenomena and for solving biomedical problems using real-life BME examples (e.g. the principles of fluid flow are illustrated by the description and modeling of cardiovascular blood flow). The BME-specific applied biological topics (category 4) start with selected advanced biological or medical topics (e.g. physiology of excitable cells) and relates them to BME applications (e.g. functional electrical stimulation of excitable cells).

The educational material delivered in the basic and applied topics differ in the emphasis on BME applications. Category 5 topics (introduction to BME or BME specialization topics) deal with an overview of the BME discipline (e.g. for introductory purposes for students entering a BME program) and with more specialized areas of BME, which may be based on the special interests of the Institution delivering the Degree material.

As is apparent from the table, it is suggested that about 60-70% of the time allocated to BME programs of type 1 and 2 should be devoted to engineering and physical sciences topics (including mathematics). For stand-alone programs of type 3 and 4 the proportion of time devoted to engineering components is reduced at the expense of increased biological and biomedical components. This is most notable in case of type 4, the emphasis reflecting the background of these students, which is purely engineering or physical sciences. Type 5 program should be regarded as a special case. Its total engineering component (including the thesis) is more than 70%, but taking into account the non-engineering past of these students it is clear that their overall engineering expertise will not be comparable to that of students from type 2-4 programs.

Topic categories from 6 to 9 are expected to be covered in about 5% of the total time allocated to the BME program. Some aspects of these topics may be incorporated within various courses. The BME research project for the thesis (10) is a very important part of any BME curriculum and should be research work carried out by all students under supervision of a skilled mentor. The research work should be complex and demanding enough so that its completion can lead to graduation thesis.

III. Core Specializations

Seven core specializations were identified as major components for BME programs of any type. The core specializations are:

- Biomaterials
- Biomechanics
- Biomedical data and signal processing
- Biomedical instrumentation and sensors
- Health technology design, assessment and management
- Information and communication technologies in medicine and healthcare
- Medical imaging and image processing

The survey carried out within CRH-BME project confirmed that the recommended core specializations appeared in most BME programs in Europe. This list of core topics also agrees with the core courses within surveys carried out in Europe and the USA. It is recommended that all 1st or 2nd cycle BME programs should cover at least four of these core topics. Instruction in the selected core specializations should be supplemented by other specializations, either drawn from the list above or reflecting the expertise of the educational institute or perceived social, health-care or industrial needs. Clear statement of the Aims and Learning Outcomes is useful for students contemplating selecting the topic and to those teaching the topic, providing a clear structure and purpose. They should also enhance and simplify mobility; the host institution clearly understands both what a guest teacher will deliver and the prior knowledge and experience of incoming students.

IV. Discussion and Conclusions

The results of our survey have shown that in the EU the number and proportion of undergraduate BME programs is increasing. The review of the existing educational programs in BME in Europe, reveals that Biomedical Engineering programs experienced a rapid growth after the year 2000 and especially during the last five years. The study identified that Biomedical Engineering programs are available in 40 European countries. Approximately 150 Universities across Europe offer in total more than 300 BME programs (~30% BSc, ~50% MSc, ~20% PhD) which is 3 times greater compared to year 2000. It can be expected that this trend will continue as a response to an increasing demand of health sector and relevant industry demand for BSc-level BME graduates. A recent study in the US revealed that BME job is by far on a first place occupations with the largest percentage growth expected through 2018 [4]. This increased demand and rapid emergence of new technologies in biomedical instrumentation both require an interdisciplinary approach to problem solving.

Another survey we carried out on the content of the courses taught in the existing BME programs in order to map the current situation and to compare it to the results of similar studies in the past. It was observed that no significant departure from the situation has occurred over the years in terms of courses. The results of the survey were then used as the basis for discussions and to facilitate the definition of the core curriculum for BME programs. The results have also shown that there are significant differences between the existing study programs in terms of total duration (in years). For this reason and from the harmonization point of view, the duration (or student "load") of the programs is specified only in terms of ECTS. Furthermore, only the minimum total number of ECTS is prescribed for each program with an important notion that the total number of ECTS of any combination of 1st and 2nd cycle programs must be at least 300, as required according to the Bologna declaration, corresponding to approximately 5 years of continuing study.

Acknowledgment

CRH-BME "Curricula Reformation and Harmonisation in the field of Biomedical Engineering" Project Number: 144537-TEMPUS-2008-GR-JPCR (2008-4527) is a Joint Project within the TEMPUS IV program and is 95% financed by the Commission of the European Communities.

References

[1] European Credit Transfer and Accumulation System (ECTS). Available: http://ec.europa.eu/education/lifelong-learning-policy/doc48_en.htm

[2] R. Magjarevic, I. Lackovic, Z. Bliznakov, N. Pallikarakis, Challenges of the Biomedical Engineering Education in Europe, 32nd Annual Conference of the IEEE EMBS, August 2010, Buenos Aires, Argentina

[3] Z. Bliznakov and N. Pallikarakis, "Review of the Biomedical Engineering Education Programs in Europe within the Framework of TEMPUS IV, CRH-BME Project", presented at the 2010 The 12th Mediterranean Conference on Medical and Biological Engineering and Computing – MEDICON 2010, Chalkidiki, Greece

[4] What Will Be the Hot Jobs of 2018? Available: http://online.wsj.com/article/SB10001424052748704026204575266342935418962.html