BIOMEDICAL ENGINEERING EDUCATION AT THE FACULTY OF ELECTRICAL ENGINEERING OF THE CZECH TECHNICAL UNIVERSITY IN PRAGUE

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Abstract: In the paper, we will focus on the changes that accompany engineering profession and that must be reflected in engineering education. The most obvious ones are role of engineers in enterprises, interdisciplinarity and globalization of engineering. We will discuss this development using a case study – biomedical engineering education at the Faculty of Electrical Engineering of the Czech Technical University in Prague. During recent years many things have changed and we have acquired new experience in the area of BME. This experience can be divided into several parts: education; students' projects and theses; research; co-operation with universities, research institutes and industrial companies both in the Czech Republic and at the international level. Czech Technical University has long-term experience in education and research in Biomedical Engineering. However, the recent technological development and practical needs of health care institutions require the university to re-organize the Biomedical Engineering courses and develop new courses that correspond better with these requirements. In this paper we will discuss Biomedical Engineering research and curricula in detail.

Introduction

Biomedical Engineering (BME) is a field with growing interest in education, research and practice as well. It is obvious that in such a fast developing area as biomedical engineering it is necessary to integrate research and education not only by introducing new pieces of knowledge to students but also by active involvement of the students into the research projects and both faculty staff and students involvement in practically oriented projects developed in close cooperation with medical doctors. Involvement of faculty staff in research and practical projects helps to maintain the relevance of curricula to technological development. Involvement of students in such projects has two main effects, namely they acquire various skills necessary for their future professional career and the study is made more attractive for them because it is not purely passive reception of large volumes of knowledge. Another important aspect is close contact with clinical engineers working in hospitals that participate actively in educational process and provide us with useful feedback about knowledge and skills necessary for the clinical practice.

Challenge for Engineers

Engineers use technology to solve practical problems. The technology that they use is underpinned by scientific knowledge and principles. Engineers must therefore have [1]:

- Factual knowledge about the technology and scientific principles relevant to their branch of engineering;
- An ability to understand the context of a practical problem, and then define it in terms that can be understood and agreed by the client (usually a person from a different problem domain);
- An ability to use technology creatively to give the most effective solution to the client's problem;
- An obligation to do this ethically and in the best interests of the client; this is the basis for trust and a professional relationship.

In the old days the engineer's "client" was perhaps the company's production manager. Engineers tended to work for other engineers. Now, the engineer must deal with a much wider range of people inside and outside the company. He or she is more likely to be involved directly with the company's customer. This requires a wider viewpoint and the ability to work with a customer who often lacks technical knowledge. It is important to succeed because business success and even survival is determined by the customer.

Thus the first aspect of the challenge arises from the diversity of people inside and outside the business enterprise with whom the engineer needs to communicate. However, the engineer's professional training should provide a good basis for meeting that challenge.

The second aspect of the challenge arises from some of the recent management trends resulting from the customer-led approach to doing business.

Some of the trends, which impact directly on the practice of engineering, are [1]:

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- Total quality management;
- Business process redesign (reengineering);
- Concurrent engineering;
- Marketing;
- Team working;
- At the level of the individual – trend to empowerment – clearer responsibility.

Implications for engineering education

When we analyze the content of curricula in electrical and information engineering throughout the Europe we find that most of the courses in particular fields are very similar and satisfying requirements on technical content of engineering education. They cover all the important topics in basic sciences, as mathematics and physics, in some cases even chemistry. Then depending on the particular field, they cover specialized disciplines.

But considering the barriers and challenges mentioned in the previous section and comparing them with the curricula we do not frequently find courses that would cover at least some of the following topics: communication skills, management, ethics, legal issues, intellectual property rights, norms and standards, project management, total quality management.

In recent years we have succeeded in establishing good links with many companies and our former graduates. We have asked them about their view on the knowledge and skills, which the fresh graduates get at the university and which they miss. From this survey, it has come out that communication skills and basic orientation in legal issues are the most important topics that were missed during the study. Next to them there are intellectual property rights, project management, team working, norms and standards, and ethics.

Based on this analysis and our previous experience we have tried to implement those topics into structured curricula (3+2 according to Bologna Declaration). Some of the topics are covered by courses that are obligatory for all students at the Faculty of Electrical Engineering CTU Prague, namely Management, Project management Reliability and quality control, Team project (team work in practice). Other topics, as communication skills, legal aspects of management, ethics, psychology in management, are covered by optional courses.

These results are in compliance with the analysis and recommendations made by the consortium of the EUR-ACE European project (Accreditation of European Engineering Programmes and Graduates) [2].

Biomedical Engineering in the Czech Republic

Biomedical Engineering (BME) represents one of the typical interdisciplinary areas. It is a field with growing interest in education, research and practice as well. It links medicine, electrical engineering, information technology, and mechanical engineering together (just to mention the most important disciplines). During recent years many things have changed and we have acquired new experience in the area of BME. This experience can be divided into several parts: education; students' projects and theses; research; co-operation with universities, research institutes and industrial companies both in the Czech Republic and at the international level. However, these parts are not strictly divided; they interact and influence each other very positively.

In the context of the above mentioned facts biomedical engineering is considered a very complex field of study and field of work. That implies necessity of intensive dialogue during curricula development with representatives of professional societies acting in biomedical engineering and clinical engineers that thanks to their professional experience can contribute to high quality of course content.

In the Czech Republic, the minimum requirements on course content in biomedical engineering are defined by legal regulations (decree No. 39/2005). It is necessary to stress that the Ministry of Health Care accredits only those study programmes satisfying the requirements. Then the graduates are allowed to certain defined positions in the hospitals and health care institutions. Graduates of other study programmes must attend specialized postgraduate courses in biomedical engineering. In addition to necessary technical (engineering) knowledge and skills, the decree specifies which knowledge and skills the students have to acquire. They cover topics of:

- ethics of health care;
- administrative activities in health care service, especially in electronic documentation;
- organization and control of health care (including management of medical technology, fundamentals of medical informatics];
- fundamentals of support and protection of public health;
- first aid and ensuring health care in situations of emergency and disaster;
- in legal context of providing health care (technical legal provisions and norms relevant to health care, general legal regulations).

The program must contain practical training in a hospital as well. The students come into direct contact with patients, advanced technology, medical doctors, nurses, and engineers working in the hospital. The students learn to be team members, team leaders, to provide information, educate and perform health care education of individuals and groups and take on responsibility for provided health care. Last but not least they learn to communicate with professionals from a completely different discipline.

Biomedical Engineering Education at CTU FEE Prague

Historical Background. At the Faculty of Electrical Engineering (FEE), CTU Prague, research and

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education in the area of Biomedical Engineering, or Biocybernetics has been running for many years. In the past however, the education was running separately in two specializations, namely in Medical Equipment and Biocybernetics. Medical Equipment was a specialization in the field of Radioelectronics and was oriented towards design and construction of medical devices. It concentrated on electronic systems for measurement, diagnostics and other equipment used in medicine. Biocybernetics specialization was taught in the frame of Cybernetics and was oriented more towards a system approach, modelling and control of biological systems, correspondence between biological systems and their models, processing of biological data and utilization of artificial intelligence methods for data processing and decision support in medicine. However in recent years technology and consequently possible areas of its utilization have been developing very quickly. Therefore it has become necessary to completely revise the curricula in both specializations. Changes in the curricula are based on the analysis of experience and requirements from practice, especially health care, but also from other areas where graduates can find jobs, i.e. pharmaceutical industry; electronic industry producing medical equipment; biotechnology; software companies developing hospital information systems, clinical information systems, and other medical software. All these areas have forced their way into a more complex approach to education in the area of BME. Recently we have changed the curricula for courses in BME so that they correspond better to practical requirements and satisfy the requirements of the new legislation. These changes concern in our case master degree studies.

Stages of Study. Undergraduate study at the FEE CTU Prague [3] is in principle divided into two stages, namely bachelor studies and master studies. In the first year of study, most courses are common for all students of the FEE. Then the courses for each study branch become different. There are four basic Bachelor Degree programmes, namely Electric Power Engineering, Electronics and Communication Technology, Cybernetics and Measurement, Computer Science and Engineering. Bachelor Degree programmes last generally for three years. They are finished by a bachelor project. A Bachelor of Science degree is awarded to the successful graduates.

Master Degree programmes are planned for two semesters after bachelor studies. They are finished by submitting a Master thesis and passing the State Final Examination. A Master of Science degree is awarded to the successful graduates. There are offered following Master Degree programmes: Electric Power Engineering; Economics and Management of Electrical Engineering; Cybernetics and Measurement; Computer Science and Engineering; Telecommunications and Radioelectronics; Electronics; and Biomedical Engineering.

New Curricula for Courses in BME. As mentioned above, Biomedical Engineering is an interdisciplinary study programme in Master Degree programmes. In the frame of BME, there are courses taught by medical doctors and courses taught by electrical engineers. Doctors provide students with an introduction to anatomy, physiology, patophysiology, diagnostic and therapeutic methods in medicine. In electrical engineering courses we can identify three groups of courses according to the topics they follow, namely the courses focused on theoretical disciplines, as for example special parts of mathematics or signal theory, the courses focused on software oriented topics, as for example pattern recognition, biological data processing, and the courses focused on medical devices and technology, as for example medical devices, or design and construction of medical devices. The aim is that the students get a sufficient system view of the basic electronic equipment and its design (let us say „medical hardware“) and the information processing in the broader sense of this term - systems for data processing, evaluation of measured data and their use for diagnostic and therapeutical purposes.

At the end of their studies the students should have an idea about the complex chain starting from a patient over measurements, analysis to diagnosis and subsequent therapy based on the latest technological development in electronics and information technology, thus using all diagnostic, measuring and evaluating systems that may be used in medicine. Let us have a closer look to individual BME courses.

The course Physiology is an introductory course where the students get basic information about human skeleton, joints, and muscles. Function of individual systems is described, i.e. immunity system, cardiovascular system, respiratory system, neural system, digestive system. Principles of physiological regulations are studied. This course is followed by the course Pathophysiology where differences from normal function and their causes are studied. Following topics are discussed: pathogenesis of diseases, regressive and progressive changes, hypertrophy, tumours, genetically conditioned diseases, inflammation; monitoring of life functions; pathophysiology of blood and blood circulation, neural system, digestive system, respiratory system; aging of human organism, atherosclerosis. Other topics, as basic principles of clinical medical specialties, clinical documentation, laboratory diagnostic processes, overview of diagnostic and therapeutic methods in individual areas, are covered during practical training of students in the hospitals.

Then there are courses that are closely related to medical courses because they concentrate on processes in a human body, however from a more technical point of view. In the course Biological Signals the students acquire knowledge about native and evoked biosignals and methods of their recording, i.e. electroneurogram, electrocardiogram (ECG), vectorcardiogram, phonocardiogram, electroencephalogram (EEG), electrogastrogram, electromyogram (EMG), electrooculogram, audiometry, tympanogram, electronystagmogram. The course Biophysics covers

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topics as physical processes related to blood flow, measurement of haemodynamic parameters in vivo, properties of blood vessels, etc. Special attention is given to artificial capillary systems and their application in treatment of renal or lung insufficiency. The students learn how to measure blood pressure under various degrees of load and they will observe their own ventilation parameters. The course Physics for Therapy is focused to Over Using Syndrome problems. In addition, there is discussed pain treatment for patients with cancer. A significant space is dedicated to electrotherapy, physiotherapy and phototherapy. Also healing processes, organ conservation methods and progressive surgery methods are discussed. Students also acquire practical knowledge in laboratories. The main aim of the course Chemical Engineering and Thermodynamics is to provide students with basic knowledge from chemistry, electrochemistry, physical chemistry and thermodynamics necessary to follow the related subjects of biomedical engineering. It deals with chemical principles of biological phenomena and their measurement, electrodes for analysis of body liquids and biopotential recording, osmosis, diffusion, thermodynamics of biochemical reactions, materials for BME, etc. Finally, it deals with basic laboratory techniques and experimental methods. The course Electromagnetic Field in Biological Systems is oriented on interactions of electromagnetic (EM) field and biological systems. Dielectric and magnetic properties of biological tissue, frequency dependence, mathematical models, and measurements are discussed. There are described electrical field in the cells and produced by the cells; bioelectrical functions of nervous, muscle and somatic cells and it's changes; impedance of biological tissue; impedance plethysmography; overview of biological effects of EM field and possibilities of its use in medicine.

Large group of courses is focused on electrical and electronic systems that are used for diagnostic and therapeutic purposes in medicine. The process of design, construction and testing of individual systems is described. Then their function and possible application areas are analyzed. The list of courses includes: Imaging Systems in Medicine; Medical Technology; Design, Construction and Reliability of Medical Equipment; Biomedical Sensors; Devices and Their Programming.

Next group of courses concentrates on software systems that may be used for modelling and simulation of biological systems and processes, processing of biological data, information processing in medicine, control of mechanical and electronic systems in medicine, decision support and intelligent monitoring. Following courses are taught: Databases and Networks; Pattern Recognition and Image Processing; Biological Data Processing, Artificial Intelligence for Medicine; Simulation and Modelling.

Optional courses include: Medical Applications of Microwaves; Introduction to Laser Physics; Biomaterials; Robotics; Ecology; Computer Vision and Virtual Reality; Biometry and Statistics; Cognitive Processes.

The last group of courses represents non-technical problems related with biomedical engineering. The aim of the course Project Design and Management is to get the students knowledgeable with all parts and phases of project management: starting from utilisation of various information resources, teamwork, technical communication, project goal specification. feasibility study, development process definition, risk analysis, capacity and resource planning, project timing, versioning, system of changes and its management, revisions, verifications, project qualification, and personal and financial project management. During the seminars the students get a challenging chance to get basic practical skills with a sample project.

The aim of the course Health Care Organization and Legislation is to provide students with knowledge of health care structure and financing in the Czech Republic. Further there are discussed problems of information systems in health care, technical and legal aspects linked with their application, and development, production and distribution of medical technology as well. It includes following topics as well: strategic planning of biomedical and rehabilitation technology; evaluation of technical equipment; international standards; certification of medical equipment; producers of medical equipment; insurance companies; ethics.

The course Medical Ethics provides students with orientation not only in general ethical problems but also in ethical questions connected with human life, health, disease and dying and medical interventions above all. Integral part of the course are discussions in which students can react both to topics from lectures and questions of the day and search for responses. Another part of the seminars should be training of skills how to conduct argumentation about practical questions according to general logical rules.

Individual and team projects of the students constitute inseparable part of the educational process. At the beginning, the students get specification of a practical problem and during one semester they have to solve it. They discuss the proposed solution with their teachers, both engineers and medical doctors. Thus they learn to communicate with specialists from other disciplines. Finally, they write a report and have a presentation. In that way, such a project work covers practical training in finding relevant information from different information sources, formulating one's own ideas, communication with colleagues and specialists, and presentation in larger audience.

At the end of their studies the students should have an idea about the complex chain starting from a patient over measurements, analysis to diagnosis and subsequent therapy based on the latest technological development in electronics and information technology, thus using all diagnostic, measuring and evaluating systems that may be used in medicine. They

ISSN: 1727-1983

should be able to orientate themselves in both technical and non-technical problems linked with technology application in medicine as well.

Potential Jobs for Graduates

As we have already mentioned, medicine is not the only application area for BME graduates. They can use their knowledge in other areas, e.g. in the development of new medicaments in the pharmaceutical industry where it is very important to use the latest electronic technology. The same holds true for a number of other areas having close links to biotechnology, ecology, the development and production of electronic systems and software systems.

Even the most sophisticated devices can be used on their own or as part of a more complex system. One aim of education in BME is to give students the system approach so that they are able to integrate individual devices into larger systems working on a qualitatively higher level than a single device. In this way it is possible to integrate already operating stand-alone devices that were bought in the past. Usually the potential of these devices is not fully used because the doctors do not understand all the technical details and therefore use just the basic functions. The electrical engineers can contribute to broader and even more efficient utilization of such a device or system.

Conclusions

It is evident that the relationship between education and research in BME must be very close. The relationship not only comprises of research results from electrical engineering but also from medicine and other relevant areas - how new diagnostic methods and devices are introduced into practice. It is necessary to include all these developments into courses for students so that they are informed about these trends and after graduation are able to work with the advanced technology in practice. It means that very good coordination is required between many different institutions, as technical universities, hospitals, and schools of medicine are.

When we have designed the curricula in BME, we have tried to take into account all the aspects of modern ways of education and the fact that BME is an interdisciplinary area. The students must have possibility to acquire team skills, including collaborative, active learning abilities, communication skills, leadership skills, and a multidisciplinary perspective during their study. Thanks to involvement in departmental and medical research, both basic and applied through the individual and team projects, they can experience research and engineering work.

Joint education between the FEE CTU and First School of Medicine, Charles University Prague means mutual inspiration and enrichment. An engineer's view on an approach to problem solving is usually different than that of a doctor. Their practical experience is different. Thus mutual exchange of experience and knowledge means new approach and contribution to solving joint practical problems. Therefore, it is very useful and enriching to participate in joint research projects between FEE and doctors, especially concerning applications of advanced electronics and informatics in medicine and other bio- branches.

Acknowledgment

The paper summarizes experience gained in electrical engineering education and biomedical engineering education and research conducted in the frame of the research programme No. MSM 6840770012 "Transdisciplinary Research in the Field of Biomedical Engineering II".

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ISSN: 1727-1983