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Educational Opportunities in BME Specialization - Tradition, Culture and Perspectives

Wasilewska-Radwanska Marta¹, Augustyniak Ewa²,
Tadeusiewicz Ryszard^{1,3} and Augustyniak Piotr^{1,3}

¹*Multidisciplinary School of Engineering in Biomedicine,
AGH-University of Science and Technology,*

²*Faculty of Humanities, AGH-University of Science and Technology,*

³*Faculty of Electrical Engineering, Automatics, Computer Science and Electronics,
AGH-University of Science and Technology,
Poland*

1. Introduction

1.1 The traditions of biomedical physics and engineering in Poland

Medical physics and engineering education in Poland started in the 1930s with the foundation of the Radium Institute in Warsaw by Maria Sklodowska-Curie. Prof. Cezary Pawlowski, one of the assistants and then collaborators of Mme Curie (fig. 1), organized the first courses in medical physics and biomedical engineering at the Physics Department of the Radium Institute.

The first course in medical engineering started at the Faculty of Electrical Engineering of the Warsaw University of Technology in the 1950s. Then, at the Faculty of Electrical Engineering, Automatics, Computer Science and Electronics of the AGH University of Science and Technology (former University of Mining and Metallurgy) in Krakow, Prof. Ryszard Tadeusiewicz organized the first courses in biomedical engineering in the 1970s. Fig. 2 shows the first Polish textbooks in Medical Electronics and in Biocybernetics. Note the year of the issue of both books, 1978.

Until the academic year 2005/2006, education in biomedical engineering was offered only as a specialization in other fields of studies, e.g. mechanics, automatics & robotics and electronics. The development of new technologies in medical diagnosis and therapy required a new approach to biomedical engineering education. Therefore, a consortium was set up of six technical universities (in alphabetical order): The AGH University of Science and Technology (Krakow), The Gdansk University of Technology (Gdansk), The Silesian University of Technology (Gliwice), The Technical University of Lodz (Lodz), The Warsaw University of Technology (Warsaw) and The Wroclaw University of Technology (Wroclaw). The consortium developed a new programme of education and then applied to the Ministry of Science and Higher Education for an official permit to create a new field of studies referred to as "Biomedical Engineering" (BME). In June 2006, the Ministry gave its consent to this proposal. The AGH University of Science and Technology was first in Poland to

enroll students in BME in the academic year 2006-2007. In 2007-2008, all the members of the consortium had students in BME. In the academic year 2010-2011, BME education is being offered by 16 technical universities in Poland (Table 1).



Fig. 1. Dated 1911. Probably one of the earliest photographs to show Maria Sklodowska Curie (first from the left), a double Nobel Prize laureate and professor at the Sorbonne (Paris), and Walery Goetel (first from the right), professor and future rector of the Mining Academy (now the AGH-UST), on a mountain trip which could have led to Maria Sklodowska Curie's becoming three years later Director of the Red Cross Radiology Service during World War I. She is also known to have converted many ordinary cars into ambulances equipped with mobile radiology units. These cars, called "petite Curie," transported X-ray apparatus to the wounded at the battle front, thus saving the lives of many French soldiers.

Medical physics education in Poland started in 1950 with the technical physics specialization created by Prof. Cezary Pawlowski at the Warsaw University of Technology, and at the AGH University of Science and Technology (former University of Mining and Metallurgy) in Krakow by Prof. Marian Miesowicz. In the 1970s, a medical physics programme was initiated at Warsaw University and at the Jagiellonian University in Krakow. In 1990, a specialization in Radiation Physics and Dosimetry was started at the AGH University of Science and Technology in Krakow, which since 1991-1992 has been run as Medical Physics and Dosimetry in close cooperation with the Collegium Medicum (Faculty of Medicine) of the Jagiellonian University. In the academic year 2010-2011, about 15 universities and technical universities offered courses for students in medical physics (Table 2).

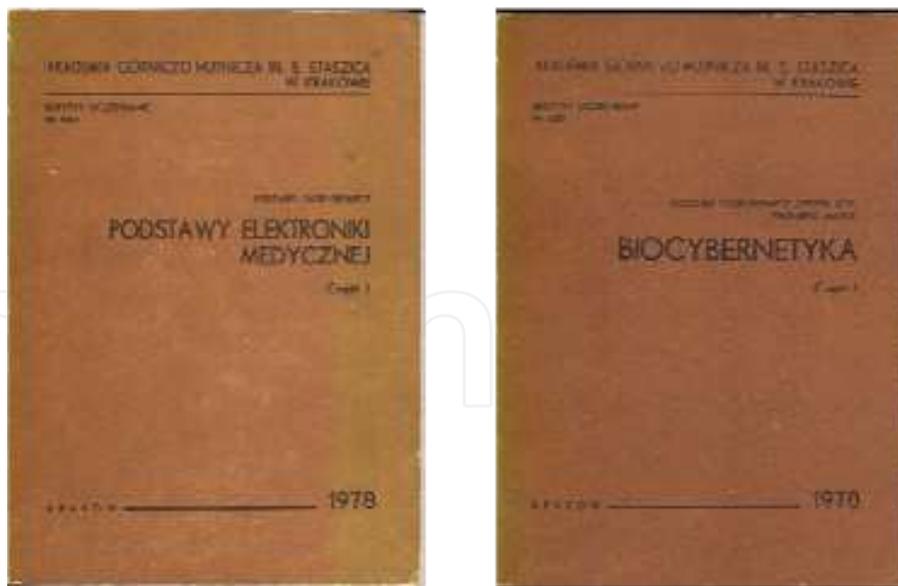


Fig. 2. The first Polish textbooks for biomedical engineering students issued by AGH-UST.

2. A multidisciplinary school – organizational background and curricula

As teaching Biomedical Engineering requires specialists representing many different areas of research and different competences, it was impossible to select a staff on the basis of the individual personnel resources of one particular faculty. Therefore to teach biomedical engineering students, a Multidisciplinary School of Engineering in Biomedicine (MSIB – the acronym used in all Polish documents describing the aims and the scope of the school) was founded (fig. 3). Below you will find the general outline of the structure and main guidelines for the School (Wasilewska-Radwanska & Augustyniak, 2009).



Fig. 3. Rector of the AGH-UST, Professor Ryszard Tadeusiewicz, signs the MSIB foundation act (2005).

2.1 The external situation

The external situation in Poland in 2005, when the Multidisciplinary School of Engineering in Biomedicine was founded, provided several opportunities and challenges (Augustyniak 2008). These initial external conditions can be classified into three groups:

The first group referred to Polish medical technology-related enterprises and/institutions:

- Local industry was rather undeveloped; we estimate the number of local medical technology-related enterprises to be about 100, but most of them (40%) were very small businesses, so-called micro-enterprises, having 1-5 employees, or small enterprises (30%) with 6-50 employees. Bigger enterprises were usually sales- or service representatives of international corporations, without independent human resources management (fig. 4);
- The relation between research and industry was weak; the way from technical innovation to marketing of a final product was very formalized;
- The results of research done by technical universities were financially unattractive and did not match industry needs; industry management preferred independent research rather than cooperation with universities;
- The average technological level of the health care was low, with notable exceptions in some selected centers.

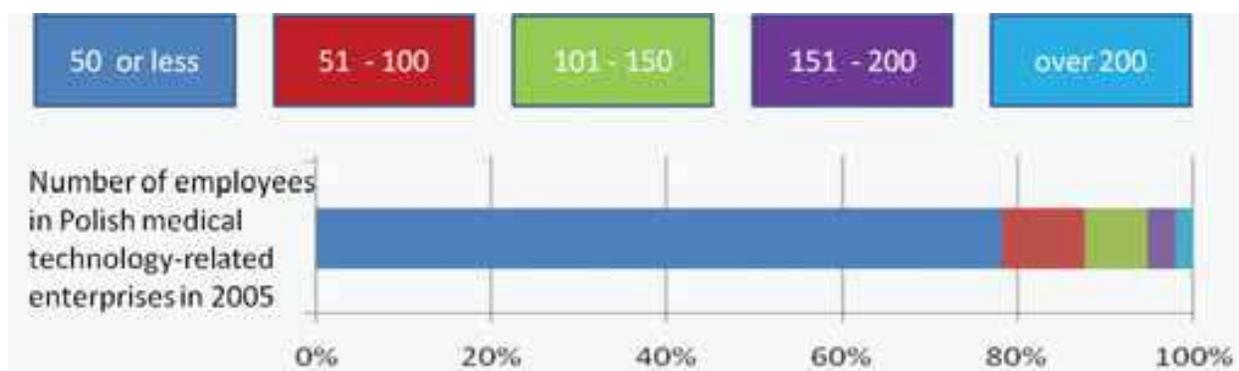


Fig. 4. The employment structure in Polish medical technology-related enterprises in 2005 (ROTMED Consortium 2006).

The second group was related to Polish medical technology needs based on social demands:

- There was an urgent and important need for the development of medical technology because of the poorer quality of social health services in Poland compared with those in highly developed EU countries (fig. 5)

The third group was related to Polish university traditions and traditional models of teaching:

- The experience with two-tier structure of degree courses/university studies (Bachelor's and Master's) was very inadequate; there were no clear guidelines for curricula, syllabuses and examinations, nor for assessment of the teaching quality; the existing government regulations were insufficient;
- There was no experience of teaching in English, and professional bibliography in Polish was very limited;
- The organizational chart of a multidisciplinary school was innovative and rarely implemented by universities, the university funds' distribution mechanisms being inadequate;

- Biomedicine-related research was carried out in several faculties within the framework of other disciplines such as computer or material sciences, electrical or mechanical engineering; there was an adequate number of professors and assistant-professors representing high-performance field-oriented output;
- The principles of school organization enabled quality-based staff selection unlimited by state employment regulations;
- There was a growing interest in medical technology from good candidates; and
- Some recent governmental regulations, aiming at improving the quality of health care, facilitated the employment of clinical engineers.

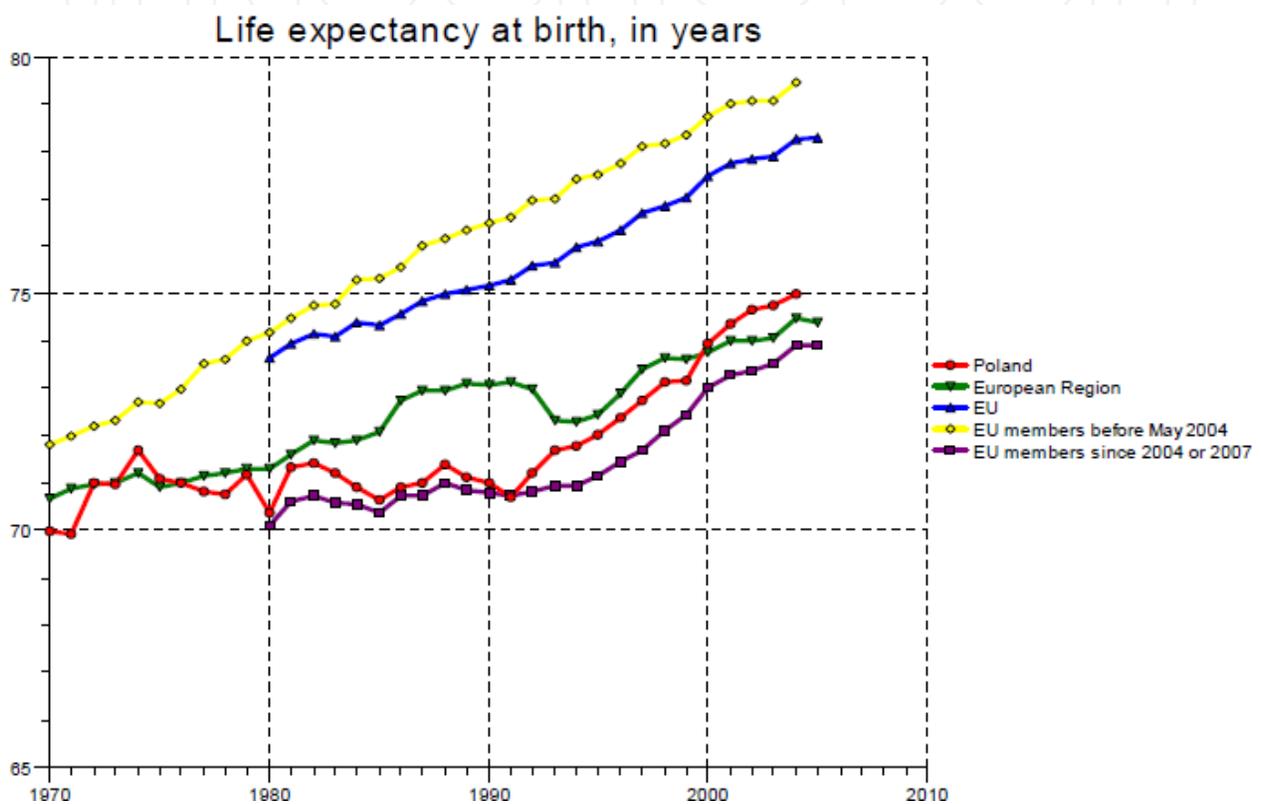


Fig. 5. A comparative plot showing the situation in social health services in Poland vs. the developed EU countries (ROTMED Consortium 2006).

All the above issues and challenges have led to ever stronger inter-university cooperation and integration into society. Representatives of eight Polish universities made every effort to establish educational standards in biomedical engineering as a separate field of study currently offered in Poland for about 1000 candidates each year.

2.2 The organizational scheme and place of MSIB in university structure

The MSIB is located at the AGH University of Science and Technology and has been in operation since the academic year 2005-2006. Although MSIB has been formed on the basis of the staff formally belonging to five faculties, it is treated as a separate part of the AGH University and has its own students. Formally, MSIB's structure is similar to that of other faculties. It is governed by a Board of 18 persons. This Board, approved by the University Senate, is made up of professors with not less than a DSc degree who are teaching at MSIB,

as well as of an adequate representation of students. At present, the professors represent five faculties:

- Faculty of Electrical Engineering, Automatics, Computer Science and Electronics,
- Faculty of Materials Science and Ceramics,
- Faculty of Mechanical Engineering and Robotics,
- Faculty of Metals Engineering and Industrial Computer Science, and
- Faculty of Physics and Applied Computer Science.

One of the Board's tasks is to recommend to the Rector appointments for the Head and the Deputy Head of the School. The appointed Head is also President of the Board. The main responsibility of the Board is to supervise the education process, assure its highest quality, verify and, if necessary, correct academic curricula, prepare staff assignments and implement other objectives of the School. The Head also represents the MSIB in the University Board on par with deans of other faculties.

From the student's viewpoint, there is no organizational difference between the faculty and the Multidisciplinary School. Both have a Dean's Office, a staff of qualified teachers, a social support system and a student board. As far as education is concerned, the rights and responsibilities of the Head of the School are identical to those of a Dean, the only difference being that research is carried out in laboratories in various faculties run by individual professors rather than in the organizational framework of MSIB.

Since medical sciences are not represented in the AGH-University of Science and Technology, six medicine-oriented lectures (e.g. anatomy, physiology, medical deontology, history of medicine) are given by professors of the Collegium Medicum (Medical College) of the Jagiellonian University. The agreement between the universities gives students the opportunity to attend lectures and to participate in laboratory exercises in the Faculty of Medicine. This cooperation is mutually beneficial since it provides an alternative, i.e. medicine-based viewpoint, for our medical colleagues and medicine students. Unfortunately, current medical curricula in Poland do not include engineering aspects in medicine, however some lecturers from AGH-UST are among those who take part in postgraduate studies and technology-oriented teaching projects for medicine students or medical doctors.

2.3 General layout of curricula

The BME teaching programs in the Multidisciplinary School of Engineering in Biomedicine AGH University of Science and Technology follow all the Polish legal regulations, including the national standards for academic teaching set out by the Ministry of Science and Higher Education (Ministry of Science and Higher Education 2007), and the guidelines of the Bologna Process (including the Educational Credits Transfer System and Accumulation System-ECTS). The current program presented in the block diagram in Fig. 6 consists of:

- A single 7-semester track leading to the First (Undergraduate) Degree (Bachelor's/Engineer's);
- Five domain-oriented 3 or 4-semester tracks leading to the Second (Graduate) Degree (Master's);
- A single 8-semester track leading to the Third Degree (Doctor's).

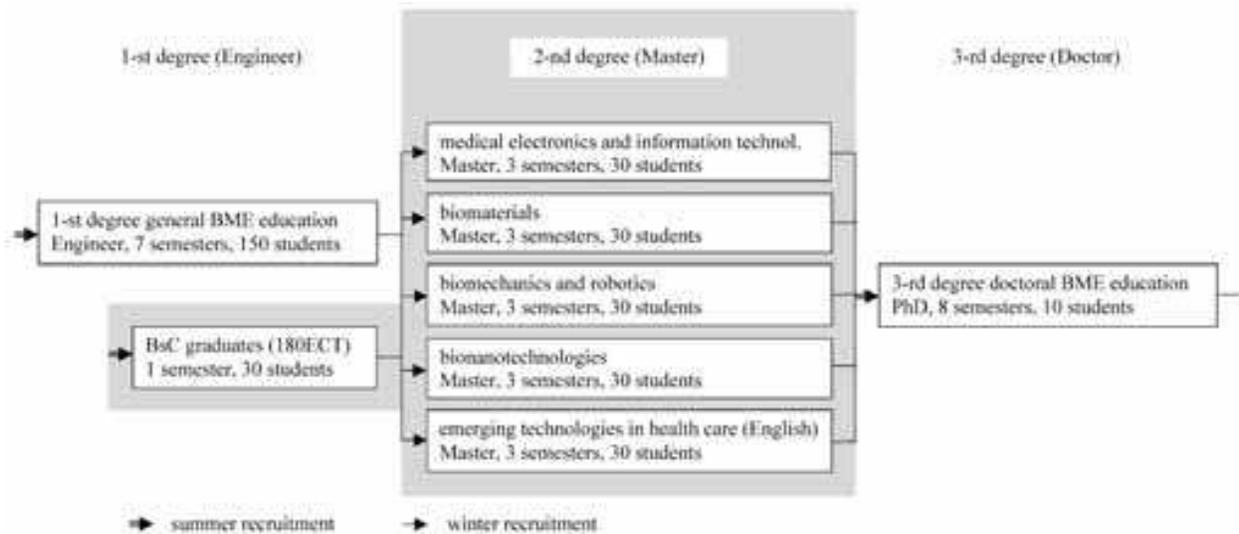


Fig. 6. An education track block diagram for biomedical engineering at MSIB AGH-UST.

After a careful review of the needs from prospective employers' point of view, the availability of existing infrastructure and resources and a detailed study of reports from more experienced colleagues, we have decided to formulate and put into practice several rules and mechanisms that provide a broad basic education in all possible BME domains and fast adaptation of the program to the variability of an unstable, constantly developing local employment market.

A complete description of the offer consisting of 189 lectures [64 for the Bachelor's (First) degree, 104 in five domains for the Master's (Second) degree and 21 for the Doctor's (Third) degree] is available from the MSIB web service www.biomed.agh.edu.pl (see Appendix, table 3). By way of example, we have selected two curricula for the specialization called "Emerging Health Care Technologies" taught in English for the Master's Degree and for the Doctor's Degree (PhD) studies (see Appendix, table 4) and three course sheets -syllabuses (see Appendix, table 5). Some selected themes for PhD theses may also be worth mentioning:

- 3D Reconstruction of Brain Glial Cells (2010),
- Automatic Facial Action Recognition in Face Images and the Analysis of Images in the Human-Machine Interaction Context (2009),
- 3D Segmentation of Medical Data from Computed Tomography and Endoscopic Video Records (2008).

Full texts of these theses are available on-line from the Biomedical Engineering PhD students' web service www.embio.agh.edu.pl.

2.4 Program adaptation mechanisms

In addition to the Bachelor's Degree program of a single track (for 150 students each year), various measures were implemented in order to increase the adaptation range of the proposed tracks. A high degree of flexibility, and a wide offer of elective courses involve students as partners in the educational process. This method of program organization with the essential participation of the students has an additional advantage: it helps to develop the students' responsibility and flexibility that is necessary in the difficult workplaces employing biomedical engineers.

The Second Degree (Master's) program (also proposed for 150 students per year) requires that students select one of five offered parallel tracks. Four of them are taught in Polish and oriented towards the main branches of biomedical engineering:

- Medical electronics and information technologies,
- Biomaterials,
- Biomechanics and robotics,
- Bionanotechnologies,
- Emerging health care technologies.

Fortunately, the formula of the multidisciplinary school that is based on human resources and the infrastructure of five faculties takes advantage of the support thus provided and is sufficient to comply with the requirements of high-quality teaching.

This variety of human and technological resources in the absence of institutional limitations and work contracts makes it possible to have a free hand in creating teaching syllabuses depending on the current market needs and students' interests. The creation of learning programs (new syllabuses and specialties) which comes under the authority of the Head of the faculty is also supplemented by three types of individual lines of study:

- Implementation of some selected additional subjects of study in addition to the standard syllabus;
- Individual schedule of study. i.e. implementation of the standard program following the accelerated or decelerated schedule, or
- Individual course of study making possible the selection of subjects outside the standard syllabus to replace elective subjects.

The creation of the course of study is based on quality indexes systematically collected from students, lecturers and employers¹. The assessment of the quality of the learning process is regularly made by:

- Estimation of current learning progress made by lecturers;
- Estimation of learning results by the Head of the Faculty based on statistical evaluation;
- Questionnaires filled in by students about their lecturers (carried out by Department Deans and made public in a adapted form to the Head of the MSIB);
- Questionnaires filled out by students on the course of their studies;
- Questionnaires on the professional abilities of students carried out in institutions responsible for the students' field work.

All the quality indexes are analyzed by the Board and are used in making the Head responsible for implementing decisions such as a face-to-face talk with the lecturer, change of the lecturer, modification in the sequence of subjects or a change in the syllabus.

3. Specific characteristics of BME-related corporate culture

Although every profession has its own best business practices, biomedical engineering has some specific characteristics. This relatively new discipline bridges the gap between medicine and technology, and, by applying various novel methods and techniques, directly influences the duration and quality of human life (Schwartz 1988). Consequently, a single medical procedure involves multiple actors, many of whom, mainly engineers, usually remain behind the scene. The cooperation between engineers and members of the

¹ In future

medical profession can succeed only if they all share some common understanding about their roles and mutually dependencies. Moreover, a medical procedure requires, among other things, technical excellence and high ethical awareness of the participating engineers. Finally, the clinical engineer frequently works shoulder to shoulder with medics in an emergency and under time pressure, burdened by stress and responsibility, where common feelings, ideas and behavior are a decisive factor in the final result. Therefore three key aspects may be identified as those related to BME professional culture:

- Understanding and good cooperation within a multidisciplinary team;
- Striving for the technical excellence and
- Human-centric ethical background.

As such circumstances are specific to this profession, the need for the organizational culture is fairly high. In case of a biomedical engineer, however, the relations are far more complex than the schemes sketched by corporate culture promoters for a typical customer service (Denison & Mishra, 1995). The above-mentioned elements of the BME-related corporate culture cannot be formed only as spontaneous forms of behavior of clinical engineers. They must be prepared by special methods and techniques of teaching and learning to help young students become highly qualified and well-prepared specialists also in the ethical dimension of their work. This process of ethical formation must be closely combined with professional skill formation, because ethics is not simply an additional competence of the future biomedical engineer, but rather a crucial element determining the use of basic knowledge in all practical applications. Therefore teachers who teach biomedical engineering students must take this additional demand into account (Augustyniak E. & Augustyniak P. 2010).

3.1 Mutual understanding and good cooperation within a multidisciplinary team

Biomedical engineering integrates various technical disciplines, but it also assumes the presence of an engineer in every situation where medicine is being practiced. Therefore, one of the principal requirements is the ability to work in a multidisciplinary team, in which common ideas, values and behavioral patterns have a very practical implication influencing the emergency response, adaptation to conditions of any healthcare mission and a sense of intellectual curiosity about technological development. In such teams, various professional learning-related particular interests are present, and mutual understanding instead of competition is the key to success.

The organizational culture of the School created by all workers from various departments of the School fosters an emphasis on teamwork and intercommunication, especially in the group of specialists from various fields. Common understanding, personal involvement and dedication constitute an essential pattern of a learning organization. In a team which includes a physician, nurse, pharmacist and an engineer, the effective use of knowledge and skill by separate persons is dependent on the mutual understanding within each person's field of competence. In addition, the cooperating specialists motivate each other and thus create novel solutions resulting from the synergy of various experiences.

3.2 Striving for technical excellence

Working in a team with a doctor, a nurse and a pharmacist, the biomedical engineer is responsible for all technology-related ideas, and is perceived as someone capable of solving

all problems in his or her area of responsibility; all of this combined may become a source of abnormal stress. Moreover, the support of life, as no other application of technology, has a direct relation to the human being, his or her health and happiness and to fundamental values. Consequently, an assumption of excellence distinguishes a biomedical engineer from engineers of other specialties. Furthermore, since technology is currently responsible for the ever greater efficiency and effectiveness of medicine, it can also be blamed for any adverse effects of medical procedures.

Striving for excellence at all levels of the implementation of detailed goals of achieving cooperation and suggesting technical solutions to problems is a typical characteristic of the organizational culture. In addition to tasks involving the implementation of educational programs (curricula and syllabuses), one of the School's main objectives is to transmit standards. Thus, when the School becomes an archetype or model of the future workplace and the lecturers employed by the School are expected to set an example of how excellence should be achieved, the care taken to provide a proper form of the organizational culture is a *sine qua non* educational requirement (O'Reilly & Chatman, 1996). If the future graduate student acquires adequate competences during the course of his or her studies, their position will be determined in a multidisciplinary team in real situations in health services. Organizational rules and regulations that are in force in the School, which employs lecturers from various faculties, make the presentation of the lecturers' various roles in the learning process easier by taking into account the person's specific knowledge, skills and attitudes. This approach has been used to make an analogy pointing to the technical excellence of an engineer as a basic argument supporting his or her key role in the multidisciplinary team employed in health services.



Fig. 7. Students discussing laboratory projects (2008).

3.3 The ethical background

Engineers who are specialists in other fields of technology than medical or biological engineering are rarely confronted with human life in its various forms and stages, such as birth, adolescence, disablement, disease, pain, death, etc. Therefore, special forms and patterns of education should be dedicated to attitudes about human nature in general. Since the engineering process in biomedicine is always part of a medical procedure, the ethical aspects of medicine should be a mandatory element of lectures and practical work in a BME-teaching institution.

The attitudes, norms and values promoted in the organizational culture of the School have an effect on the way how the future graduates will think and act in their professional life. The sense of responsibility and reliability combined with a sense of humanitarianism, curiosity and creativity are among the most desirable attributes of a biomedical engineer, while also held in high value by employers in other fields. The above values are not easily transferable to traditional university teaching methods such as lectures, problem-solving or experiments, therefore elements of the organizational culture may be of some help in this context.

The most important elements of this culture are:

- Forms of a specific tradition established within a given group to strengthen the feeling of identifying with the group's aims;
- Undertaking novel professional activities such as writing textbooks, promoting the new profession in mass media or encouraging volunteer work by both lecturers and students;
- Permanent evaluation of the School's activity and the teaching and learning programs based on external assessment and the opinions provided by lecturers and students.

4. Opportunities and perspectives of BME-teaching institutions

The MSIB authorities have designed a unique, well-balanced corporate culture program and continue to develop it with success. The MSIB itself as a teaching institution was started from scratch, so from the beginning it was based on the general principles of a learning organization.

4.1 A blueprint for an organizational culture

The establishment of a new institution created an opportunity for devising a profession-specific, independent system of shared values and beliefs implying and reinforcing a collective identity centered on the mission of the biomedical engineer. Our aims exceeded "standard faculty" programs, providing students with government-designed minimum curricula. Our main objective is for MSIB to become a leading research and educational center (Augustyniak et al. 2010). Despite a relatively short history of only five years, the School has undoubtedly earned high marks in Poland and has become well-recognized abroad. This was possible due to:

- Employment of the best professionals in the field as teachers;
- Active creation of cooperation links with other universities in Poland and abroad;
- Publication of a BME-student quarterly - a periodical promoting the profession and reinforcing the students' intellectual confidence and emotional group commitment;

- Leadership and promotion of common activities, exchanges, encouragement of staff and students' mobility, additional lectures etc.;
- Dissemination of knowledge and participation of staff members in international conferences and their activity in commissions and other opinion-forming bodies.



Fig. 8. Professor Zbigniew Kakol, Rector of AGH-UST, confers an Engineering Diploma (2010).

The organizational culture of the MSIB is based on a deeply motivated concept of a high-quality teaching and learning institution, aiming at the education of marketable BME professionals (Gordon & DiTomaso, 1992). The School is student-friendly and supports students' educational initiatives in various fields of activity. What is expected and/or requested from the staff and students are well-defined goals to achieve. In this spirit, thanks to the common sense of responsibility, the internal atmosphere in the School supports cooperation rather than competition.

To make common attitudes and values more popular and generally recognized, the organizational culture of the MSIB offers the following:

- Ceremonies (matriculation, the Dean's address at the New Year, summarizing achievements challenges, and future plans, etc.);
- Corporate design (a well-recognized logo, a precisely defined color, organizational badges for Board members, corporate T-shirts for students);
- Outstanding personalities - undoubtedly this honor goes to Professor Ryszard Tadeusiewicz, the founder of the School and former Rector of AGH-UST, a pioneer in biomedicine and author of several BME-related books since the mid-70s;
- Common recreational activities (mountain trekking, sailing, skiing, student sports teams in various disciplines, volunteer-based events in hospitals and hospices, initiatives on behalf of the handicapped, extramural students' organizations and forums).

The corporate culture is built on selected values and behavioral norms that influence both the employees and students through the internal and external institutional policy. The commonly accepted standards constitute the internal ambience and friendliness of the School, but as a long-term investment become everyday habits. We easily observe teachers transferring these standards to their own departments, which justifies the belief that in the future the graduates will also promote such standards in their workplaces.



Fig. 9. Informal mountain trekking of MSIB students and the Dean (first from the left).

4.2 The employment perspectives of graduates

The high quality of educational outcomes is of vital interest for students, their prospective employers and university staff. All three groups of partners aim for a common goal using different approaches and capabilities. Cultivating the understanding of the School as a common value and sharing the collective identity and commitment reinforces compatibility and multi-professional team building. This training field for interpersonal learning reveals three enhancing feedback loops:

- Attractive employers increase students' motivation and good graduates extend the development perspectives of their employers;
- Innovative employers offer career opportunities for good researchers in applied sciences, and more effective professors provide high-quality knowledge to industry which in turn enhances the university's reputation;
- Good candidates are inclined to look for good lectures and challenging projects, and become a source of professional satisfaction to professors who make efforts to improve their lectures.

These relations, demonstrated above in a simplified form, are fundamental for the team-building spirit, which is based on the commitment of students, tutors and professionals to a quality-focused efficient education. In the MSIB, the healthcare professionals participate in the preparation of curricula, provide opportunities for one-month internships and formulate challenges for young teams of scientists. The university staff cultivates the students' creativity by supervising laboratory exercises and interim projects which constitute a demonstration of the graduates' skills, and can be partly applied in healthcare and industry. The excellence of the university staff in science is also a good example attracting best students who often try to follow or to participate in research themselves.

The most highly appreciated educational initiatives are those focused on education-oriented basics, behavioral norms and values including self-teaching. Equally important to scope and breadth of knowledge are technical skills and human-centric attitudes. The basics of human sciences, ethics and law are indispensable elements of education and practice of the School. Two other important features are:

- Flexibility which makes it possible for the School to adapt itself to changing trends of the employment market and which enables graduates to keep pace with quickly-developing technical sciences; and
- A set of relations between the teacher and/or the dean and the student which focuses on communication and exchange of information. This not only makes relations within the School administration easier but also establishes a pattern for future relations in a multi-professional environment.

Current employment perspectives mostly result from the growing importance of extensive use of technology in health care. Clinical engineer, manufacturing engineer, researcher and sales representative are the four main types of specializations in terms of future professional careers. Nevertheless, local employment markets are weak, and the effort to raise the awareness of a new profession to a higher level is among the principal concerns of the MSIB Management. General statistics are favorable for the AGH-UST graduates: 75% of them find their first job within one month after graduation, and 95% within three months. According to other surveys, in 500 of Poland's biggest enterprises, AGH-UST graduates constitute the second largest percentage among senior management staff.

5. Concluding remarks

The special demands imposed on BME education require that we should seek unusual organizational solutions and non-standard teaching and learning methods, related to the specific and unique educational challenges posed by BME. We hope that these theoretical and practical methods and techniques developed at the MSIB and presented above may be of interest to other educational institutions in BME field.

6. Acknowledgments

This work was supported by the Rector of the AGH University of Science and Technology in Krakow, Poland. The authors want to express their gratitude to the Walery Goetel family for their consent to publish the archival photo of Maria Skłodowska Curie.

7. Appendix

Institutions	Faculty/ Department	Organisation (current state)/specializations
AGH Univ. of Science and Technology (Krakow)	Electrical Eng., Automatics, Comp. Sc.& Electronics	Multidisciplinary School of engineering In Biomedicine (MSIB)/Med. Electronics&Inform.; Biomat.; Biomech.&Rob.;Bionanot; ; Emerging Techn.Health Car
Bialystok Univ. of Techn.(Bialystok)	Mechanical Engineering	/Biomechanics; Rehabilitation Engineering; Medical Materials
Czestochowa Univ. of Techn. (Czestochowa)	Mechanical Engineering & Comp. Sc.	Rehabilitation Engineering; Medical Informatics.
Gdansk Univ. of Technology (Gdansk)	Electronics, Telecommunications &Informatics	Inter-Faculty full-time studies /Inf.Med.; ElectrM.; ChemM; PhysM
Koszalin Univ. of Techn. (Koszalin)	Institute of Mechatronics, Nanotechnology& Vac. Techn.	/Implants; Medical Instrumentation; Manipulators
Krakow Univ. of Technology (Krakow)	Mechanical Engineering	/Clinical Eng. Dental Biomechanics; Biomechanics of Injuries
Lublin Univ. of Techn. (Lublin)	Mechanical Engineering	In cooperation with Lublin Medical Univ./CT; MR; Aut&Rob; Biomat Art Organs; M Electr ;Infor in Medicine
Lodz Univ. of Techn. (Lodz)	El., Electronic, Comp.& Control Eng.	Inter-Faculty Education Centre with the Fac. of EL, Electronic, Comp.& Control Eng./Biomats; Biocorrosion; Biomeasurements
Poznan Univ. of Techn. (Poznan)	Mechanical Engineering&Management	Mechatronics/ Biomedical Engineering
Silesian Univ. of Technology (Gliwice)	Biomedical Engineering	/ InformaticsM; M Electr.;Sensors & Biomed;; Implants Reahabilitation
Silesian Univ. (Katowice)	Computing Sc. and Material Sc.	/ Biomed.Inform;; Med. Imaging; Telemed&Clinical Inform. Systems;
Warsaw Univ. of Technology (Warsaw)	Mechatronics/ I. of Metrology&Biomed. Engineering and Electronics and Information Technology	Inter-Faculty studies:e F. of Mechatronics& F. of Electronics&Inf. Techn./Biomech.; Biomat.s; Biomed. Sensors; Biomed.Imaging; Rehab.Eng; ;Prostheses&Art Organs; Clin.Eng. ; Biotechnology; Medical Informatics
Wroclaw Univ. of Technology (Wroclaw)	Fund. Problems of Technology	/Electromed Equip; Smart Transducers; ; Fiber Optics&d Lasers in Med.Equip.; Computer MDiagn.
Zielona Gora University (Zielona Gora)	Mechanics; Electrical Engineering, Comp.Sc.&Telecommunic.;; Biological Sc.	Inter-Faculty studies. /Medical Informatics; Medical Electronics; Biomechanics; Biomaterias
Bydgoszcz Univ. of Tech. (Bydgoszcz)	Mechanics	/ Technical Medical Consulting; Medical Informatics
West Pomeranian Univ. of Techn. (Szczecin)	Electrical Engineering	/ Biomedical and Acoustic Engineering

Table 1. A list of institutions which provide education in Biomedical Engineering (BME) in Poland (since academic year 2010-2011).

Institutions	Faculty/ Department	Discipline	Specialization
Univ. of Bialystok (Bialystok) www.uwb.edu.pl	Physics	P*	MP
Univ. of Gdansk (Gdansk) www.ug.gda.pl	Math, Physics & Informatics in cooperation with Gdansk Medical Univ.	MP*	MP
Univ. of Silesia (Katowice) www.us.edu.pl	Math., Phys. and Chem.	MP	Clinical Dosimetry; Optics in Medicine; Electroradiology
Jan Kochanowski Univ. of Humanities and Sc. (Kielce) www.ujk.edu.pl	Math.&Sc.	P	MP
AGH Univ. of Sc. & Techn. (Krakow) www.agh.edu.pl	Phys.& Appl. Comp. Sc.	MP	Dosimetry and Electronics in Medicine; Imaging and Biometrics
M. Curie-Sklodowska Univ. (Lublin) http://mfi.umcs.lublin.pl	Math., Phys. Comp. Sc.	P	Molecular and medical biophysics
Un. of Lodz (Lodz) www.uni.lodz.pl	Phys& Chem.	P	MP
Techn.Univ.Lodz (Lodz) www.p.lodz.pl	TPhys., Comp Sc.& Appl.Math.	TP*	MP
Univ. of Opole (Opole) www.wmfi.uni.opole.pl	Math., Phys & Chem.	MP	MP
Adam Mickiewicz Univ. (Poznan) http://amu.edu.pl	Physcis	B****	MP
Ignacy Lukaszewicz Techn.Univ. (Rzeszow) http://portal.prz.edu.pl	Math.& Appl. Physics	TP	Physics and Informatics in Medicine
Univ. of Szczecin (Szczecin) www.us.szc.pl	Math.& Physics	P	Biomedical Physics
Nicolaus Copernicus Univ. (Torun) www.umk.pl	Phys., Astr& Informatics	MP	MP and Comp. Appl.
Warsaw Univ. (Warsaw) www.uw.edu.pl	Physics/Inst. of Exp.Phys.	APBM*****	MP
Warsaw Univ. of Techn. (Warsaw) www.pw.edu.pl	Physics	TP	MP
Wroclaw Univ. of Techn. (Wroclaw) www.pwr.wroc.pl	Fund. Problems of Techn.	TP	Nano-engineering
Univ. of Wroclaw (Wroclaw) www.uni.wroc.pl	Physics and Astr.	TP	MP

*)MP=Medical Physics ; **) P=Physics ; ***)TP=Technical Physics; ****)B=Biophysics;
*****APBM=Applications of Physics in Medicine and Biology

Table 2. A list of institutions which provide education in Medical Physics (MP) in Poland (since academic year 2010-2011).

semester	First Degree(Bachelor's)	semester	First Degree (continued)
1.	<ul style="list-style-type: none"> • Information technologies • Mathematics • Physics • General chemistry • Biocybernetics • Biology and genetics • Propedeutics of medical sciences 	5.	<ul style="list-style-type: none"> • Foreign languages • Medical Physics Biomechanics • Computer graphics • Fundamentals of graphical programming languages • Programming languages -or- Object programming • Automatics and Robotics
2.	<ul style="list-style-type: none"> • Mathematics • Physics • Statistics and probability theory • Principles of electrical engineering • Principles of electronics • Organic chemistry 	6.	<ul style="list-style-type: none"> • Foreign languages • Biomechanics - project • Implants and Artificial Organs • Electronic Medical Instrumentation • Medical Imaging Technology • History of medicine • Elective 1 - Cryptography and data ciphering systems - Chemometry - Ergonomics and occupational medicine • Elective 2 - Principles of management in biotechnical systems - Microcontroller programming in C/C++ - Globalization and modernization problems - Introduction to environmental philosophy - Glass- and glass-ceramic materials in medicine
3.	<ul style="list-style-type: none"> • Sport • Foreign languages • Physics laboratory • Materials sciences • Principles of metrology • Mechanics and strength of materials • Fundamental anatomy • Principles of physiology • Computer programming 	7.	<ul style="list-style-type: none"> • Introduction to diagnostics with ionizing radiation • Medical deontology • Introduction to philosophy • Legal and ethic issues in biomedical engineering • Diploma seminar • Engineering project and examination for Bachelor's degree • Elective 3 - Biomineral science - Practical electronics - Programming of control and measurement systems
4.	<ul style="list-style-type: none"> • Sport • Foreign language • Computer Aided Design -or- Design with Finite Elements Method • Elements of Biochemistry • Biophysics • Biomaterials • Sensors and non-electrical measurements -or- Integrated measurement systems • Digital signal processing 		

Table 3. (a) Syllabus of the First Degree (Bachelor's) studies in biomedical engineering

semester	Second Degree (Master's)		
	medical electronics and information technologies	biomaterials	biomechanics and robotics
1.	<ul style="list-style-type: none"> • Identification and modelling of biological structures and processes • Tissue and genetic engineering • Fundamentals of telemedicine • Neural networks • Electronics Systems for Clinical Applications • Information systems in health care • Picture archiving and communication systems • Elective 1 - Design of VLSI circuits - Multimedia systems in medicine - Advanced methods for programming of multithreaded applications 	<ul style="list-style-type: none"> • Clinical trials • Ceramic Biomaterials • Polymer Biomaterials • Identification and modeling of biological structures and processes • Tissue and genetic engineering • Information systems in health care • Implantation technologies • Elective 1 - Electron microscopy in biomedical engineering - Neurochemistry and neuropharmacology 	<ul style="list-style-type: none"> • Biomedical signals processing • Identification and modelling of biological structures and processes • Tissue and genetic engineering • Rehabilitation Technology • Biomechanical designs • Servomechanisms and advanced control systems • Control systems in medical devices • Visual surgery support techniques
2.	<ul style="list-style-type: none"> • Research of biomaterials and tissues • Dedicated medical diagnostics algorithms • Multimodal interfaces • Rehabilitation Technology • Medical imaging systems • Telesurgery and medical robots • Individual project • Elective 2 - Algorithms for medical image analysis and processing - Cognitive informatics 	<ul style="list-style-type: none"> • Research of biomaterials and tissues • Composite biomaterials • Metallic biomaterials • Telesurgery and medical robots • Rehabilitation Technology • Fundamentals of applied crystallography • Individual project 	<ul style="list-style-type: none"> • Research of biomaterials and tissues • Ergonomics • Intelligent materials and structures • Acoustical diagnosis • Information systems in health care • Telesurgery and medical robots • Image processing for surgery support • Individual project
3.	<ul style="list-style-type: none"> • Voice computer communication • Computer support for acoustic diagnostics • Fundamentals of embedded systems design • Diploma seminar • Master thesis and examination 	<ul style="list-style-type: none"> • Fundamentals of regenerative medicine • Diploma seminar • Master thesis and examination • Elective 3 - Selected problems of neurobiology - Surface engineering 	<ul style="list-style-type: none"> • Bionics • Pharmaceutical industry equipment • Diploma seminar • Master thesis and examination • Elective 3 - Computer aided of engineering - EPLAN - Pharmaceutical industry materials and designs - Nanotechnology

Table 3. (b) Syllabus of the Second Degree (Master's) studies in biomedical engineering.

semester	Second Degree (Master's)	
	bionanotechnologies	emerging health care technologies
1.	<ul style="list-style-type: none"> • Symmetries and structures, solid body and molecules • Soft tissue physics • Polymers • Physics of thin film surfaces • Identification and modeling of biological structures and processes • Tissue and genetic engineering • Physical methods in biology and medicine • Information systems in health care • Elective 1 - Biotechnological challenges in biophysics - Instrumental analysis methods - Fundamentals of cell and tissue engineering - Structural backgrounds of cell biology 	<ul style="list-style-type: none"> • Biomaterials and artificial organs • Electronics Systems for Clinical Applications • Information systems in health care • Physical methods in biology and medicine • Telemedicine and e-health • Tissue and genetic engineering • Assisted Living Technologies
2.	<ul style="list-style-type: none"> • Research of biomaterials and tissues • Magnetic nanomaterials • X-ray applications in biomedicine • Applications of magnetic resonance in biomedical research • Telesurgery and medical robots • Rehabilitation Technology • Introduction to radiobiology • Individual project 	<ul style="list-style-type: none"> • Design of biomechatronical systems • Identification and modeling of biological structures and processes • Medical imaging systems • Research of biomaterials and tissues • Rehabilitation Technology • Telesurgery and medical robots • X-ray applications in biomedicine • Development of VLSI systems • Individual project
3.	<ul style="list-style-type: none"> • Optical method of matter investigation • Neuroelectronics • Diploma seminar • Master thesis and examination • Elective 3 - General and molecular genetics - Protein engineering - Leukocyte and cancer cells transportation - Fluorescent and confocal microscopy - Molecular modeling of bioparticles - Photobiology and photomedicine 	<ul style="list-style-type: none"> • Implantation Techniques • Introduction to Biometrics • Neurochemistry and neuropharmacology • Diploma seminar • Master thesis and examination

Table 3. (c) Syllabus of the Second Degree (Master's) studies in biomedical engineering.

semester	Third Degree (Doctor's)
1.	<ul style="list-style-type: none"> • Graph theory • Methods of systems optimization • Biocybernetics • Medical sensors and measurements
2.	<ul style="list-style-type: none"> • Graph theory • Methods of systems optimization • Medical imaging in clinical practice • Biometry and medical statistics
3.	<ul style="list-style-type: none"> • Information systems in telemedicine • Biomechanics i acoustics • Biomedical digital signal processing • Biomaterials and artificial organs
4.	<ul style="list-style-type: none"> • Electronic medical instrumentation • Medical physics
5.	<ul style="list-style-type: none"> • Medical image analysis • Modeling of biological systems
6.	<ul style="list-style-type: none"> • Electives (2 of 6) - Dedicated algorithms for biosignal interpretation - Integrated systems SoC in medical diagnostics and therapy - Intelligent sensor arrays - Biophysics - Biological interfaces - Advanced equipment in medicine and rehabilitation
7.	<ul style="list-style-type: none"> • Philosophy / Economy
8.	<ul style="list-style-type: none"> • individual research

Table 3. (d) Syllabus of the Third Degree (Doctor's) studies in biomedical engineering.

Table 4. (b) Syllabus of Third Degree (Doctor's) studies in biomedical engineering.

Postgraduate BME studies AGH – TRACK TA discipline "biocybernetics and biomedical engineering"

Id	Course name	Professor <i>(confidential)</i>	year I		year II		year III	
			Sem.1	Sem.2	Sem.3	Sem.4	Sem. 5	Sem.
Common courses								
1	Graph theory		30	30				
3	Methods of systems optimization		30	30				
5	Philosophy / Economy							
Discipline-oriented courses								
6	Biocybernetics		30					
7	Medical imaging in clinical practice			30				
8	Medical sensors and measurements		30					
9	Biometry and medical statistics			30				
3bi1	Information systems in telemedicine				30			
3bi2	Biomechanics and acoustics				30			
3bi3	Biomedical digital signal processing				30			
3bi4	Biomaterials and artificial organs				30			
4bi1	Electronic medical instrumentation					30		
4bi2	Medical physics					30		
5bi1	Medical image analysis						30	
5bi2	Modeling of biological systems						30	
6bi1	Dedicated algorithms for biosignal interpretation							30
6bi2	Integrated systems SoC in medical diagnostics and therapy							
6bi3	Intelligent sensor arrays							30
6bi4	Biophysics							
6bi5	Biological interfaces							
6bi6	Advanced equipment in medicine and rehabilitation							

 msib		Medical imaging systems		Master (MSc) Level Recommended course Biomedical Engineering	
Coordinating person:	Prof. dr hab. inż. Ryszard Tadeusiewicz	Teaching team:	Dr inż. Przemysław Korohoda Dr inż. Zbigniew Bubleński		
Department:	Automatics and Control		Year/Semester: 5/9		
Lecture language: English					
Lecture hours: 30 h		Laboratory/Exercise hours: 1/1	Hours per week: 2/-/1/1		
Expected knowledge					
Elements of signal and image processing, elements of computer science, basic physics, fundamentals mathematical analysis and algebra of vectors and matrices					
Principal aims					
Theoretical and practical presentation of principal aspects of medical images acquisition (different methods!), filtering, storing, transmission, processing, segmentation, analysis, recognition, and also automatic understanding					
Teaching rules					
Lectures are given in auditory and supported by additional e-learning material, Students participate in 7 laboratory exercises presenting various aspects of telemedicine, students are expected to solve a particular measurement or methodological problem, Students working in supervised teams are expected to develop a custom project or to solve a complex practical problem under given conditions.					
Progress evaluation rules					
Report-based score after each laboratory exercise. Project evaluation based on report and practical presentation.					
Lecture description					
<ol style="list-style-type: none"> 1. Introduction to medical images acquisition methods 2. X-ray images and properties 3. CT – computer tomography 4. MRI – magnetic resonance imaging 5. SPECT, PET – nuclear imaging methods 6. USG – ultrasonography 7. TG – thermography 8. Endoscopic visualization 9. Medical images registration and transmission. DICOM standard 10. Medical images filtration and denoising 11. Image segmentation 12. Image analysis and diagnosis aid 13. Image recognition 14. Medical images automatic understanding 15. Conclusions 					
Bibliography					
<ol style="list-style-type: none"> 1. Burger W., Burge M.J. eds.: Digital Image Processing - An Algorithmic Introduction using Java. Texts in Computer Science series. Springer Science + Business Media, New York, 2008 2. Baert A. L., ed.: Encyclopedia of Diagnostic Imaging. Springer-Verlag, Berlin - New York, 2008 3. Ogiela M. R., Tadeusiewicz R.: Modern Computational Intelligence Methods for the Interpretation of Medical Images, Studies in Computational Intelligence, Volume 84, Springer-Verlag, Berlin – Heidelberg – New York, 2008 4. Tadeusiewicz R., Ogiela M. R.: Medical Image Understanding Technology, Series: Studies in Fuzziness and Soft Computing, Vol. 156, Springer-Verlag, Berlin – Heidelberg – New York, 2004 5. http://www.medical-image-processing.info/ 6. http://mipav.cit.nih.gov/ 					

Table 5. (a) Syllabus of the course "Medical imaging systems" (Second Degree-Master's).

		Research of biomaterials and tissues		Master (MSC) Level Compulsory course Biomedical Engineering	
Coordinating person:	Dr hab. inż. Anna M. Ryniewicz, prof. AGH	Teaching team:	Dr hab. inż. Anna M. Ryniewicz, prof. AGH Dr inż. Tomasz Madej		
Department	Department of Machine Design and Technology		Year/semester: 4/8		
Lecture language:	English				
Lecture hours: 15 h		Exercise/Laboratory: 15h	Hour per week: 1 L, 1 lab.		
Expected knowledge					
The subject requires knowledge from the fields of the materials science, technology and use of biomaterials, the analysis of biomechanical extortion, histology and physiology of tissues.					
Principal aim					
The aim of the subject is the study the research methods and the estimation of biomaterials in the aspect of application of carrying construction, stabilizing and biodegradation.					
Teaching rules					
The lectures in the range of two hours per week are carried out in the form of multimedia presentations and precede in its matter laboratory study, which is also realized in two hours per week after the completion of laboratory cycle.					
Progress evaluation rules					
The credit is obtained on the basis of positive note from test and the positive particular notes from laboratory jobs.					
Subject description					
Lecture: Biomechanics of human locomotive and stomatognathic systems. The Doppler methods of testing the flow. Criteria of biomaterials selection. The methods of testing biomaterials resulting from the function in human body. The mechanical tests of biomaterials and tissues: testing of resistance by static and dynamic loads and the tribological tests. Ultrasonic tests. The methods of testing the surface layer structure of biomaterials and tissues in micro, macro, nano scale using new research techniques (optical microscopy, scanning electron microscopy SEM and scanning transmission electron microscope STEM, roentgen diffraction, photoelectron spectroscopy, atom force microscopy AFM, tunnel microscopy, infrared spectroscopy The analysis of contact: bone tissue – implant. The analysis of stresses and displacements distributions in the numerical models with the purpose to obtain optimization of selection of implant and estimation the state of tissues effort. Biocompatibility tests. The correlation between in vitro tests, tests on animals and application tests. The standards that regulate the estimation of biocompatibility. Laboratory: The reconstruction of three-dimensional geometry of regular hip joint and implanted endoprosthesis in pathological hip joint on the basis of imaging diagnostics (MR CT) using Amira software. The estimation of working and kinematics parameters of movement of hip joint using HIP98 software. The development of strategy and testing of resistance on compression and bending of bone tissues using testing machine INSTRON. The testing of resistance on compression and bending of selected biomaterials on testing machine INSTRON. The tribological research of selected biomaterials and cartilaginous tissue on testing machine ROXANA The testing of adhesion of multilayer biomaterials on testing machine INSTRON. The comparison of conditions of transfer of loads in endoprosthesis of hip joint made from different biomaterials using finite element method FEM.					
Bibliography					
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Table 5. (b) Syllabus of the course "Research of biomaterials and tissues" (Second Degree-Master's).

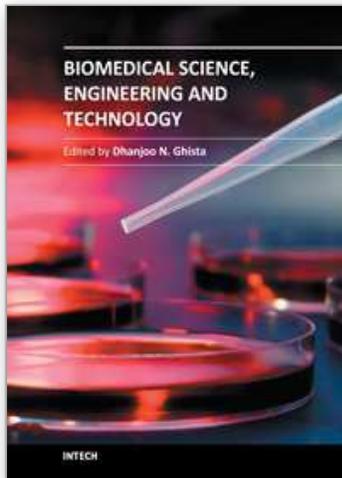
		Tissue and genetic engineering		Master (MSc) Level Compulsory course Biomedical Engineering	
Coordinating person:	Dr hab. inż. Elżbieta Pamuła	Teaching team:	Dr hab. inż. Elżbieta Pamuła Dr Elżbieta Menaszek Mgr inż. Małgorzata Krok		
Department	Department of Biomaterials		Year/Semester: 4/8		
Lecture language: English					
Lecture hours: 15 h		Laboratory/Exercise hours: 15/15	Hours per week: 2/2/4(4 weeks)		
Expected knowledge					
Basic knowledge of biology, genetics, biochemistry, materials science, biomaterials, implants and artificial organs					
Principal aims					
Introduction to key issues of tissue engineering and genetic engineering					
Teaching rules					
2-h lectures are given every second week Students participate in 2-h seminars every second week Laboratories are blocked: students participate in four 4-h exercises					
Progress evaluation rules					
Test (lecture), oral presentation (seminars) and reports (laboratories)					
Lecture description					
Scope of tissue engineering. Cell and tissue cultures, in vitro techniques, bioreactors. Cell types and sources. Growth factors. Extracellular matrix as a biological scaffold for tissue engineering. Interactions at the interfaces: materials/biomacromolecules/cells/tissues. Methods to investigate material/biological environment interface. Scaffolds design and fabrication. Tailoring structure, microstructure and surface properties of scaffolds for cell and tissue culture. Tissue engineering in vivo – guided tissue regeneration. Tissue engineering products (skin, cartilage). Genetic engineering and gene therapies. Enzymes (restriction endonucleases, ligases), expression vectors, gene cloning. Construction and analysis of recombinant DNA. Molecular probes. Expression of cloned genes. DNA amplification by PCR. DNA sequencing. Genetic engineering products (synthetic human insulin, synthetic human erythropoietin, insects or herbicide resistant plants).					
Seminars					
Based on the most recent publications the students elaborate and present a particular topic related to tissue and/or genetic engineering.					
Laboratories					
The students are introduced to elementary rules of cell cultures. They learn how to count mammalian cells in suspension and analyze their viability. They seed cells on different biomaterials, and following a short incubation and staining cell adhesion, morphology and secretion are evaluated. The students are also introduced to in vitro biomaterials evaluation methods and cytotoxicity tests.					
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Table 5. (c) Syllabus of the course "Tissue and genetic engineering" (Second Degree-Master's).

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This innovative book integrates the disciplines of biomedical science, biomedical engineering, biotechnology, physiological engineering, and hospital management technology. Herein, Biomedical science covers topics on disease pathways, models and treatment mechanisms, and the roles of red palm oil and phytochemical plants in reducing HIV and diabetes complications by enhancing antioxidant activity. Biomedical engineering covers topics of biomaterials (biodegradable polymers and magnetic nanomaterials), coronary stents, contact lenses, modelling of flows through tubes of varying cross-section, heart rate variability analysis of diabetic neuropathy, and EEG analysis in brain function assessment. Biotechnology covers the topics of hydrophobic interaction chromatography, protein scaffolds engineering, liposomes for construction of vaccines, induced pluripotent stem cells to fix genetic diseases by regenerative approaches, polymeric drug conjugates for improving the efficacy of anticancer drugs, and genetic modification of animals for agricultural use. Physiological engineering deals with mathematical modelling of physiological (cardiac, lung ventilation, glucose regulation) systems and formulation of indices for medical assessment (such as cardiac contractility, lung disease status, and diabetes risk). Finally, Hospital management science and technology involves the application of both biomedical engineering and industrial engineering for cost-effective operation of a hospital.

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InTech Europe

University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166

InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

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