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WP1. National report (German speaking countries)

1. Trends in biomedical engineering industry and education in Europe, with an emphasis on Austria, Germany and Switzerland

Biomedical engineering is a young field of engineering and relatively small compared to the traditional engineering fields, like electrical or mechanical engineering but due to the changing needs of society, the number of biomedical engineers working in research and development is rapidly growing. That inevitable growth in the industrial sector and the corresponding demands of the labour market also means that higher education institutions realised that there is a whole new area which requires people to become professional and acquire knowledge at an early stage thus leading to more undergraduate biomedical engineering degrees in Europe. That rise in dedicated study programmes also means that biomedical engineering is likely to become an increasingly competitive field. Even those with dedicated qualifications will find themselves competing with engineers from other disciplines. Biomedical engineers should therefore be prepared to adapt to existing forecasted needs.

Obviously, there is a strong pressure on education, training and life long learning programmes to continously adapt their objecties in order to face new requirements and challenges. Today, education in biomedical engineering in Europe, is mainly influenced by a) the European policy on higher education, b) research & development programmes and c) the market demands.

Biomedical engineering involves applying engineering principles to biology, medicine and healthcare to solve problems and individuals would typically find themselves working in health services, the medical devices industry or research. While its fragmented nature makes it difficult to quantify the overall biomedical engineering sector in terms of number of people employed and its worth, the global medical devices market alone is estimated to be worth EUR 320 billion. According to the market research company Kalorama, the US accounts for around 45 % of the global bioengineering market, with the UK market being the third largest in Europe, behind Germany and France. A survey of the market shows that it is also important to consider the growing digital healthcare market. The latter is expected to be worth EUR 197,5 billion by 2020, with Asia-Pacific predicted as a key region.

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German speaking life science sector

A closer look at the Austrian life sciences sector reveals a wide ranging and diversified segment with more than 720 companies in the fields of biotechnology, pharmaceuticals and medical engineering generating 5.4 percent of the country's GDP, employing a workforce of 50,000 people. One distinguishing feature is the high level of networking among producers, suppliers and service providers.

A total of 435 companies in Austria operate in the field of biomedical engineering and are involved in a spectrum of research areas, with a particular focus on electromechanical medical technology and software development. Firms producing high quality medical products focus on hearing implants, in the development of high-tech prostheses as well as dialysis therapies and products. Thus showing that most of the biomedical industry expands and labour market for biomedical engineers is expected to grow further with the fastest developing industries currently being active implants, medical imaging and mobile health services. New opportunities open in neural engineering, in interfacing the devices and the tissue, changing the cells and building artificial organs from artificial and biological materials, organisation of large datasets from biology, etc. Austria's life science sector profits from the high diversity of the academic life science landscape across the country, with the medical device industry particularly benefitting from the long tradition in the field of engineering and precision mechanics.[1]

According to the economic development agency of the Republic of Germany (GTAI), the German medical technology industry, made up almost entirely of small and medium-sized enterprises, is highly innovative and generates a large share of its revenues from exports. In 2015, the approximately 1,200 medical device manufacturers generated EUR 27.6 billion in sales. Today, Germany is the world's third largest manufacturing nation with a share of 10.2 percent of worldwide medical technology production. This is directly behind the USA (39.6%) and China (11,1%).[2] Germany enjoys a long and successful tradition in mechanical medical

[1] https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=4&ved=0ahUKEwjP776LtovbAhUC66QKHc0ZDd0QFghCMAM&url=https%3A%2F%2Fwww.bmbwf.gv.at%2Ffileadmin%2Fuser_upload%2Fwissenschaft%2FZukunft_Hochschulen%2F8._Anlage_A_Studienangebot_Life_Sciences.xlsx&usg=AOvVaw1x_TGShbNf4LuklB_eI2jm
Accessed 14.04.2018

[2] https://www.gtai.de/GTAI/Content/EN/Invest/_SharedDocs/Downloads/GTAI/Industry-overviews/industry-overview-medical-technology-en.pdf?v=5
Accessed 05.03.2018

engineering and high quality manufacturing, producing the largest pool of talents and skilled people in Europe. Germany currenty has 23 study programmes in bio(medical) engineering.[3]

Switzerland is one of the most important locations for the global medical technology industry. There is in fact no other country in which medical technology enjoys such high status in comparison with total GDP and the working population than Switzerland. 94% of the medical equipment manufacturers in Switzerland collaborate with partners – whether they are universities, hospitals or companies from related sectors, such as in mechanical engineering or pharmaceuticals. This very specically promotes innovation. Over 500 suppliers, service providers, retailers and distributors can be found in Switzerland, along with around 300 medtech manufacturers. In 2016, there were around 1,000 individuals studying Life Sciences at the Federal Institute of Technology in Lausanne (EPFL), at Bachelor, Master or Doctorate level. In the same year, 2,600 students attended Life Science courses at universities of applied science.[4]

Demands for bio(medical)engineering education

Research and development in biomedical engineering is complex and hardly any research institution can cover all knowledge and skills necessary for the successful outcome of the research goals by itself. Problems that biomedical engineers are expected to solve vary tremendously and this diversification can only be expected to increase further with new and rapidly emerging technologies and changing demands of the health sector.

Even though the term biomedical engineer includes professionals with very heterogeneous areas of specialisation, their profiles nevertheless share common characteristics, which define and make them unique among the engineers. There is no doubt that biomedical engineers have to have a profound knowledge of fundamental engineering and physical science. Furthermore, unlike other engineers, they must be able to apply this knowledge to solve problems of medical and biological origin, which all require a multidisciplinary approach. And even more so, any biomedical engineering curriculum must include specialisation elements, which address current and future needs.

[3] See also Abu-Faraj, Z.O. (2012): Bioengineering/Biomedical Engineering Education. In: Abu-Faraj, Z.O. (Ed.): Biomedical Engineering Education and Advanced Bioengineering Learning. Interdisciplinary Concepts. Vol. 1, Hershey: Medical Information Science Reference (IGI Global), p1-60.

[4] https://www.s-ge.com/sites/default/files/cserver/publication/free/factsheet-medtech-in-english-s-ge-201709.pdf Accessed 14.04.2018

What are these needs and trends?

Bioengineering technology develops also due to the altered needs of healthcare. Population projections in Europe show a dramatic growth of elderly population: those aged 65 years or over will account for more than 30.0 percent of the EU's population by 2060. Today, healthcare industry intensifies efforts for solutions of the long-term treatments for chronic diseases in the aging patient population.

In the next decades, one can expect that research will focus on and introduce devices for restoring the functions of tissue, by more sophisticated implantable electronic devices. In the future, there will be patients with more than one implantable electronic device and these devices will have to learn how to communicate and adjust their performance in order not to cause any harm due to joint action. The next step will be functional tissue engineering with producing biological materials which have properties close to, or the same as human living tissue that can withstand the same forces and strain. Also, image guided surgery will enable precise access to the place of interest and positioning of the implant to the right position. At the same time, data transfer and information processing in medical applications will become more demanding due to increased number of sensors for measurement or monitoring of physiological and biomechanical quantities, from the surface and/or from the inside of the body. Closed loops of sensors, e.g. glucose sensors implanted into the body and external actuators e.g. the insulin pump, mimic organs like the pancreas with the intention to regulate the blood glucose level in the same way as a healthy human organ. In near future, people will learn how to design more complex integrated biological structures – the organs.
In consideration of the future scenarios, bioengineers must be prepared to adapt to those existing and/or forecasted needs.[5]

Undergraduate as well as graduate education and LLL programmes need to continuously adapt their objectives in order to meet the recent and future developments in the area of biomedical engineering, address new emerging inter-disciplinary domains that appear as a result of the R&D progress and respond to labour market demands.

[5] See also Castiho, L.R. (2017), Biopharmaceutical products: an Introduction. In: Soccol,V./ Pandey, A./ Resende, R. (Ed.): Current Developments in Biotechnology and Bioengineering: Human and Animal Health Applications. Amsterdam: Elsevier, p. 3-18.

2. Brief introduction to the higher education system in Austria, German and Switzerland

Austria

The higher education system in Austria comprises the traditional public universities with a research focus and private universities. In addition, Austria introduced “Fachhochschulen” (Universities of Applied Sciences) during the 1990s. The training at these universities is more tailored to practically applicable professional skills. Furthermore, students are allowed much less liberty in choosing which and how many courses they take during a given semester, which ensures that virtually all students graduate within the prescribed time (usually three years for the bachelor's degree).

Since the 1970s, the first degree was the Magister (= Latin for Master, abbr. Mag.) in the humanities, economic and social sciences, law and natural sciences. The first degree in engineering and agriculture is the Diplom-Ingenieur (abbr. Dipl.-Ing. or DI). Recently, and in accordance with the Bologna process, many universities have begun to introduce a bachelor's degree also, which comes before the "Magister" or Master.

However, with the Bologna process, Austria has committed to transform its system to the structure of distinguishing between Bachelor and Master degrees (of 3 years and 1–2 years respectively). In some fields, it is still not clear how this will be made compatible with the traditional requirements necessary to enter a regulated profession.[6]

Germany

Universities in Germany mainly impart theoretical knowledge. Courses are very academically oriented and there are many different subject groups. As in Austria, Universities of Applied Sciences (Fachhochschulen and Hochschulen für angewandte Wissenschaften) in Germany offer practice-oriented academic courses. The focus is more on professional application than theory, and the training is adapted to the requirements of professional life. As at universities, the first degree is the bachelor’s and the second is the master’s.

For master's courses, there is also a choice between a Master of Arts (M.A.), Master of Science (M.Sc.), and Master of Engineering (M.Eng.) etc. Degree programmes at German universities have been reformed in recent years. Though one may still come across some traditional diploma and Magister (Artium) degree programmes. They are similar to the master's degree.[7]

[6] https://bmbwf.gv.at/fileadmin/user_upload/Kasparovsky/HsSystem_201602_E_BF.pdf Accessed 20.04 2018

[7] https://www.hrk.de/activities/higher-education-system/ Accessed 20.04.2018

Switzerland

Universities in Switzerland are the traditional academic institutions for higher education. These include the cantonal universities and the Federal Institutes of Technology (FIT) managed by the Confederation. As a rule, the admission to a university requires a Baccalaureate. The studies have a scientific approach. Doctoral or PhD programmes can only be completed at a university. Universities of Applied Sciences supplement the university education and training with professionally oriented programmes. The admission to a University of Applied Sciences requires a Federal Vocational Baccalaureate, but admission with other qualification is possible. (In particular, universities of applied sciences provide access to study at tertiary level for professionals who have completed vocational education and training (VET) and hold a Federal Vocational Baccalaureate.) They provide science-based and practice-oriented education and training. Switzerland fully implemented the Bologna process and its qualification framework.[8]

8 https://www.swissuniversities.ch/fileadmin/swissuniversities/Dokumente/Kammern/Kammer_FH/Publikationen/higher_education-e.pdf Accessed 04.04.2018

3. List of study programmes in bio(medical) engineering in Austria, Germany and Switzerland

List of study programmes and courses in Austria at bachelor's level

The list of courses and study programmes presented below was compiled with regard to their relevance for the BIOART project and comprises the full curricula of four study programmes at undergraduate level, of which three are organised at University of Applied Sciences.[9]

Name of HEI and programme	**Degree awarded**	**Credits**	**Duration of study**
University of Applied Sciences Technikum Vienna **Bachelor in biomedical engineering**		**180 ECTS**	**3 years full-time**
Courses		**Credits**	
Semester 1		**30**	
Systematic and topographic anatomy		4,5	
Medical physics		3	
Physics lab		2,5	
General, organic & polymere chemistry		6	
Chemistry lab		2	
Basics of informatics & software development		1,5	
Structured programming in biomedical technology		4,5	
Mathematics 1		3	
English 1		2	
Startup (Class Kickoff)		-	
Time & self management		1	
Semester 2		**30**	
Biochemistry & molecular biology		4,5	
Biochemistry lab		1,5	
Physiology lab		1	
Medical electronics		4	
Medical electronics lab		2,5	
Functional anatomy and physiology		4,5	
Object oriented modelling		1,5	
Object oriented pogramming in biomedical technology		4,5	
Mathematics 2		3	
English		2	
Teamwork		1	
Semester 3		**30**	
Biomedical statistics		1,5	
Pathophysiology		3	
Anaesthesia, analgesia and intensive care		1,5	
Medical measuring technique basics		3,5	
Biomedical applications of simulation tools		1,5	
Introduction to medicine and hospital utilities management		1,5	
Introduction to rehabilitation technique		1,5	
Radiation Medicine		3	
Instrumental analytics in laboratory medicine		1,5	
Instrumental analytics lab		1	
Introduction to cell & tissue engineering		1,5	
Introduction to medical imaging and data processing		1,5	
Information management in medicine		4,5	

[9] https://www.technikum-wien.at/studium/bachelor/biomedical_engineering/, https://www.fh-campuswien.ac.at/studium/studien-und-weiterbildungsangebot/detail/bioengineering-bachelor.html, https://www.fh-ooe.at/en/linz-campus/studiengaenge/bachelor/medical-device-technology/study/curriculum/, https://www.tugraz.at/studium/studienangebot/bachelorstudien/biomedical-engineering/ Accessed 17.02.2018

English 3	2
Moderation & problem solving techniques	1
Semester 4	**30**
Experimental design	1,5
Animal model	1,5
Basics of technical and biomedical regulation	2,5
Biomedical and technical control loop	2
Biological regulations	1,5
Elective module 1 (specialisation)	12
English 4	2
Job application	1
Project, process and quality management	3
General law & regulations	3
Specialisation cell & tissue engineering	
Molecular Genetics	3
Pharmacokinetic and Toxicology	1,5
Cell Culture Techniques	1,5
Cell Culture Laboratory	3
Immunology	1,5
Bioinformatics	1,5
Specialisation rehabilitation engineering	
Neural engineering	3
Biomechanics	3
Gaitanalysis	3
Circuit design and signal analysis	3
Specialisation medical & hospital engineering	
Medical application of embedded systems	3
Biological Signals and medical sensors	3
Radiation physics	3
Engineering heart, lung and circulation	3
Specialisation medical imaging & data engineering	
Safety and communication in medical data engineering	3
Telemedicine & eHealth	3
Medical imaging and analysis	3
Medical data engineering	3
Semester 5	**30**
Elective module 2 (specialisation)	15
English 5	2
Ethics in technology and medicine	1
Conflict managment	1
Business administration	3
Spezielle Rechtskunde	3
Writing biomedical research papers & reports	3
Bachelor thesis seminar	2
Specialisation cell & tissues engineering	
Bioassays	3
Tissues Engineering	3
Cell biology	4,5
Morphological methods	4,5
Specialisation rehabilitation engineering	
Gaitanalysis project	3
Prosthetics	3
Modelling and simulation	3
Ambient assisted living and communication technology	3
Rehabilitation engineering and neurorehabilitation	3
Specialisation medical & hospital engineering	
Biological signals and medical sensors	3
Human-computer interaction	1,5
Medical and hospital equipment	3
Nuclear medicine and radiation therapy	3
Photonics in biomedical engineering	1,5
Radiation protection	3
Specialisation medical imaging & data engineering	
Application of medical imaging and data engineering	4,5
Signal acquisition and analysis	4,5
Mobile computing in medical imaging and data engineering	3
Bioinformatics	3
Semester 6	**30**
Bachelor thesis seminar	2
Internship (incl. report)	28

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Name of HEI and programme	Degree awarded	Credits	Duration of study
University of Applied Sciences FH Campus Vienna **Bachelor in bioengineering**	**Bachelor of Science in Engineering (BSc)**	**180 ECTS**	**6 semesters, part-time**

Courses	Credits
Semester 1	**30**
General microbiology	4
General and inorganic chemistry	5
Analytical and physical chemistry	3
General chemistry I (practical course)	1
Introduction to organic Chemistry	2
Mathematics	4
Microbiological microscopy (practical course)	1
Physics	3
Statistics for chemical analysis	3
Stoichiometry and quantitative chemical analysis	2
Tutorial in mathematics	2
Semester 2	**30**
Bioorganic chemistry	3
General chemistry II (practical Course)	2
General chemistry III (practical Course)	4
Hydraulics and fluid mechanics	2
Mechanical engineering	5
Microbiologic methods	1
Organic chemistry	4
Specific microbiology	4
Technical mathematics	4
Technical drawing, mechanical engineering	1
Semester 3	**30**
General Microbiology (practical course)	3
Biochemistry	4
Introduction to the biochemical exercises	1
Electrical engineering	3
Mechanical engineering II	4
Thermo-mechanical process engineering VO	4
Molecular genetics and strain development	4
Tutorial for calculations in process engineering UE	2
Calculations in process engineering	5
Semester 4	**30**
Bioanalytics	3
Biochemistry (practical course)	3
Calculations in bioprocess engineering	2
Brewing and fermentation technology	4
Basics of bioprocess engineering	4
Measurement, control -and sensor technology	3,5
Programming and bioinformatics	3,5
Technical microbiology	3
Cell biology	4
Semester 5	
Applied statistics	2
Introduction to GMP and quality management	2
Molecular genetics (practical course) - project preparation	1
Molecular genetics (practical course)	3
Practical course: fermentation technology	5
Quality control	2
Statistics (practical course)	4
Animal cell technology	2
Specialisation: informatics	
Biointormatics	1
Bioinformatics data analysis (statistics)	2
Programming	6
Specialisation: bioprocess technology	
Facility design and automatisation	5
GMP practical course	4
Semester 6	
Specialisation: bioprocess technology	
Facility design, GMP-project, Bachelor thesis SE	10
Downstream processing (practical course)	1

General courses	
Aseptic filling	1
Practical training PR	7,5
Plant hygiene VO	2
Downstream-processing, metabolites VO	2
Downstream-processing, proteins VO	2
Fermentation (practical course) LB	2
Practical training - reflection SE	0.5
Specialisation: informatics	
Linux based systems and data base	1
Programme design, automation, bachelor thesis	10

Name of HEI and programme	**Degree awarded**	**Credits**	**Duration of study**
University of Applied Sciences Upper Austria **Bachelor in medical device technology**	**Bachelor of Science in Engineering (BSc)**	**180 ECTS**	**6 semesters**

Courses	**Credits**
Semester 1	**30**
Anatomy	3
Medical terminology	1
Physiology	4
Chemistry and biochemistry I	4,5
Lab I	1
Mathematics I	5
Physics I	2,5
Medical technology	3
Electrical technology I	2
Informatics I	5
English for medical engineering I	2
Optional courses	
Field visit MEDICA	1
Programming basics	1,5
Healthcare technology management	1
Semester 2	**30**
Hygiene	1
Pathology	2
Chemistry and biochemistry II	2,5
Lab II	1
Mathematics II	5
Physics II	3,75
Electrical engineering II	3,75
Informatics II	2,5
Programming I	2,75
Technical mechanics	3,75
Function principles of medical engineering I	2
Optional course	
Workshop project	2
Semester 3	**30**
Biomechanics	3,75
Electronics	3,75
Medical materials	2
Modelling and computer simulation	3,75
Applied device and rehabilitation technology I	2,5
Biosignal processing	3,75
Function principles of medical engineering II	2
Function principles of medical engineering II / Lab I	1,5
Medical software and information systems	2,5
English for medical engineering III	2
Semester 4	**30**
Electronics II	2,5
Measurement and regulation technique I	2,5
Programming II	2,75
Applied device and rehabilitation technology II	4,5
Functional principles of medical engineering III	2
Functional principles of medical engineering III / Lab II	1,5
Safety engineering	2
Bachelor thesis I	1
Electives	

Circuit technology and EMV I	3,75
Biomechanics experimental lab	3,75
Machine-oriented device programming	3,75
Microscopy	3,75
Devise construction	3,75
Exo-prosthetics	3,75
Semester 5	
Medical engineering internship/practical course	2
Project management and risk analysis	2,5
Medical devices act, regulations and standards	3
Social competences I and presentation skills	2,5
Semester 6	
Hospital utility management	1
Technical Quality assurance	2
Bachelor thesis II	1
Integrative project management	6
Measurement and control technique II	5
English for medical engineering IV	1
Health economics	1
Product management	2
Hospital quality management	1
Law basics for medical engineers	1
Social competences II	1,5
Electives	
Circuit technology	2,5
Numeric methods and FEM	2,5
Sensory materials	2,5
Medical-electrical systems	2,5
Device supported rehabilitation technology, electrical stimulation and health care technology	2,5

Name of HEI and programme	**Degree awarded**	**Credits**	**Duration of study**
Technical University Graz **Bachelor in biomedical engineering**	**Bachelor of Science (BSc)**	**180 ECTS**	**6 semesters**

Courses	**Credits**
Preliminary courses	**11,5**
Introduction biomedical engineering	0,5
Functional anatomy	2,5
Basics in informatics	4
Physics	4,5
Basics in medicine and biology	**11,5**
Functional anatomy	2,5
Physiology and und pathophysiology	3
Basics in biochemistry	3
Basics in molecular and cell biology	3
Basics in natural science	**42**
Mathematics A (ET)	9
Mathematics B (ET)	9
Mathematics C (ET)	4,5
Probability theory, statistics and Data analysis	5
Technical numerics	6
Physics	5,5
Chemistry basics	3
Basics in informatics	
Basics in informatics	5,5
Informatics 1	4
Informatics 2	4
Scientific Computing: MATLAB	3,5
Basics in engineering	**41,5**
Basics of electrical engineering	6
Basics of electrical engineering / Lab	**3**
Biomedical system and control theory	4
Signal processing	4,5
Measurement technique 1	3

Measurement technique / Lab	3
Electrical circuit technology 1	3
Electrical circuit technology 2	**3**
Electrical circuit technology /Lab	2
Mechanics - statics	3
Mechanics - dynamics	2
Basics in biomedicine	**31,5**
Biophysics	5,5
Basics in biomechanics	4
Basics in biomedical technology	6
Basics in biomedical technology / lab	4
Material science	3
Diagnostic imaging procedures	3
Medical device safety	3
Biomedical sensor systems	3
Soft skills, life sciences	**13,5**
Introduction to biomedical engineering	0,5
Bioethics	1,5
Systems engineering and project management	1,5
Scientific writing	2
Bachelor project biomedical engineering	8
Optional subject	**9**
Optional course according to § 6b	9
Electives	**14 of 23**
Computational intelligence	4,5
Strength of materials	4,5
Computer graphics 1	2,5
Computer vision 1	2
Hospital utility managment	3
Bio- physical modelling	2
Data structure and algorithms	3
Data structure and algorithms	1,5

List of programmes and courses in Austria at master's level

The list comprises four study programmes at master's degree level of which two are organised by traditional universities and the other two at universities of applied sciences.[10]

Name of HEI and programme	**Degree awarded**	**Credits**	**Duration of study**
University of Applied Sciences Upper Austria Master in Biomedical Engineering	Dipl.Ing. (=MEng)	120 ECTS	2 years full-time
Courses		**Credits**	
Semester 1		**11,25**	
Applied Mathematics I		3,75	
Selected Topics in Medicine for Medical Engineers I		1,25	
Applied Mathematics II		2,5	
Analogue Circuit Design		2,5	
Embedded Systems I		2,5	
3D Kinematics		2,5	
Modelling and Simulation of Multibody Systems		2,5	
Applied Programming I		2,5	
Applied Software Life Cycle Processes I		2,5	
Materials		5	
Current Topics in Biomedical Engineering		2,5	
Medical Diagnosis Systems I		5	
Prosthetics and Rehabilitation Technology I		2,5	

[10] https://www.fh-ooe.at/campus-linz/studiengaenge/master/medical-engineering/, https://www.technikum-wien.at/studium/master/biomedical_engineering_sciences/, https://www.tugraz.at/studium/studienangebot/masterstudien/biomedical-engineering/, https://www.tuwien.ac.at/en/teaching/master_programs/biomedical_engineering/ Accessed 02.03.2018

Optional courses	
FDA Regulatory Affairs	0,3
Scientific Programming	2,5
Semester 2	
Selected Topics in Medicine for Medical Engineers II	1,25
Statistics and Clinical Trials	2,5
Embedded Systems II	2,5
Power Supply Systems	2,5
Biomechanical Laboratory	2,5
Numerical Methods	2,5
Applied Programming II	2,5
Applied Software Life Cycle Processes II	2,5
Molecular Test Systems	2,5
Surface Technology	2,5
Medical Diagnosis Systems II	2,5
Prosthetics and Rehabilitation Technology II	1,5
Therapeutical Systems	3,5
Regulatory Affairs I	1,25
Optional course	
Health Technology Assessment	1,25
Semester 3	
International Product Management	2
Project Tutorial	1,25
Project: Scientific or Professional	18
Regulatory Affairs II	2,5
Requirements and Usability Engineering	2,5
Systems Engineering	3,75
Optional course	
Semester 4	
Master's Thesis	27,5
Master's Tutorial	2,5
Optional course	
Journal club	2,5

Name of HEI and programme	**Degree awarded**	**Credits**	**Duration of study**
University of Applied Sciences Technikum Vienna Medical engineering & eHealth	Master of Science in Engineering (MSc)	120 ECTS	4 semesters full-time

Courses	**Credits**
Semester 1	**30**
Applied Biomedical Engineering in Projects	8,5
Economic & Legal Issues	5,5
Engineering in Medicine	8
Elective Module 1	**8**
Advanced Programming for Medicine (APM)	4
Biomedical Engineering for Therapy & Rehabilitation (BETR)	4
Medical Information Systems (MIS)	4
Modelling in Cardiovascular Systems (MCVS)	4
Semester 2	**30**
Applied Biomedical Engineering in Projects 2	7
Processes for Medical Device and System Design	8
Scientific Methodology in Biomedical Sciences	**8**
Applied Biomedical Engineering in Projects 2	7
Elective Module 2	**8**
Advanced Optics (AO)	4
Artificial Intelligence (AI)	4
Electromagnetic Compatibility (EMC)	4
Informatics of Biological Systems (IBS)	4
Semester 3	**30**
Advanced Clinical and Data Engineering	8
Exploring the BME Industries	4
Methods of Scientific Research	10
Elective Module 3	**8**
Applied Optics in Medical Devices (AOMD)	4
Biomedical Engineering in Respiration (BER)	4
EEG Acquisition and Analysis (EEG)	4
Image Analysis (IA)	4
Semester 4	**30**
Master's thesis	30

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Name of HEI and programme	Degree awarded	Credits	Duration of study
Technical University Graz **Master in biomedical engineering**	**MSc**	**120**	**2 years**

Courses	Credits
Major component	**50**
Minor component	**21**
Optional courses (related to minor)	**10**
Master's degree seminar	**3**
Master's thesis	**30**
Optional courses to be chosen out of the elective catalogue	**6**
Elective module biomechanical engineering	**Major: Biomechanics: Modelling and Simulation** **Minor 1: Biomaterials**
Prerequiste courses	2
Computer Vision 1	4.5
Strength of Materials	
Theory of Materials / Structural Analysis	
Tissue Engineering	3
Theory of Materials	3
Biological and Bio-based Materials	3
Imaging Laboratory	3
Electron Microscopy Imaging	1.5
Bionanotechnology	3
Microscopy in Biotechnology	4
Materials Characterization II	2
Materials Characterization III	2
Physics of Modern Materials	3
Medical Image Analysis	5
Biomaterials	3
Pathology	3
Multiscale Biomechanics	
Mechanics of Biological Tissues	3
Mechanics of Proteins and Cells	3
Basics of Biomechanical Modelling and Simulation	
Continuum Mechanics	4,5
Fluid dynamics and heat transfer I	8
Fluid dynamics and heat transfer II	5
Advanced fluid dynamics and heat transfer	3
Thermodynamics for Biomedical Engineers	5
Advanced Thermodynamics	5
Basics of Numerical Methods (Finite Element Method) and Applications	
Optimization for Computer Science	5
Finite Element Method	3
Finite Element Method - Advanced course	3
Computational Biomechanics	5,5
Technical Numerics 2	4
Numerical methods in fluid dynamics and heat transfer	4,5
Numerical methods in applied thermodynamics	3
Partial differential equation and numerics	4
Biostatistics and Experimental Design	3
Elective module biomedical instrumentation and sensors	**Major: Biomedical Instrumentation and Sensors** **Minor 1: Biomolecular Analytics** **Minor 2: Medical Electronics** **Minor 3: Bioinstrumentation**
Signal processing	
Biosignal Processing	6
Nonlinear Signal Processing	5
Analytics / Biosensors	
Chemical Analytics and Sensors	4.5
Molecular Diagnostics	5

Physics of Modern Materials	3
Bionanotechnology	3
Biomaterials	3
Biomedical Instrumentation Basics	
Medical Instrumentation	3
Medical devices technology	3
Biomedical Sensor Systems 2	2
Control of Medical Instrumentation	3
Rehabilitation Engineering	3
Medical Laser Technology	3
Introduction to Brain-Computer Interfacing	1.5
Biomedical Sensor Systems, Laboratory	3
Biomedical Instrumentation Project	6
EMC of Electronic Systems	3
EMC of Electronic Systems, Laboratory	3
Instrumentation Specialization	
Telecommunication engineering	7,5
Foundations in high frequency engineering	5
Energy technology for biomedical engineers	3
Microcontroller	4
Practical Analog Circuit Design	4,5
Circuit Simulation	4,5
General Skills	
Development and Design of biomedical Devices	3
Predictive Healthcare Information Systems	3
Medical devices act	3
Encyclopedia Business Economics	7,5
Biostatistics and Experimental Design	3
Elective module Biomedical Imaging and Sensing	**Major: Biomedical Imaging and Sensing** **Minor 1: Optical Microscopy** **Minor 2: Biomedical Imaging**
Computergrafik 1	2,5
Computer Vision 1	2
General Skills	
Encyclopedia Business Economics	7,5
Medical devices act	3
Pathology	3
Foundations	
Biological Control, Modeling and Simulation	6
Inverse Problems in Medical Imaging	5
Optimization for Computer Science	5
Imaging and Sensing Methods	
Magnetic Resonance in Medicine and Biology	3
Selected Chapters in Bioimaging	3
Imaging Laboratory	3
Biooptics	3
Microscopy	3
Microscopy (Lab Course)	1,5
Electron Microscopy Imaging	1.5
Chemical Analytics and Sensors	1.5
Biomedical Sensor Systems, Laboratory	4.5
Biomedical Sensor Systems 2	3
Molecular Diagnostics	5
Methods of Functional Brain Research	3
Signal and Data Processing, Analysis and Management	
Biostatistics and Experimental Design	3
Biosignal Processing	6
Nonlinear Signal Processing	8
Medical Informatics	3
Non-Invasive Brain-Computer Interfaces	6
Image Processing and Visualization	
Prerequisite	
Computer graphics 2	2,5
Computer Vision 2	2,5
Image Processing and Pattern Recognition	5
Medical Image Analysis	5
Biomedical Visualization	3
Elective module Computational Neuroscience	**Major: Computational Neuroscience** **Minor 1: Brain-Computer Interfacing**

	Minor 2: Neural Engineering
Prerequisite	
Computational Intelligence	4,5
Foundations	
Information Processing in Humans	3
Neurophysiology & Information Processing in Human	1
Cognitive Neuroscience	3
Methods of Functional Brain Research	3
Biosignal Processing	6
Nonlinear Signal Processing	5
Biostatistics and Experimental Design	3
Brain-Computer Interfaces	
Introduction to Brain-Computer Interfacing	1,5
Non-Invasive Brain-Computer Interfaces	6
Non-invasive Brain-Computer Interfaces 2	3
Neurocomputing, Seminar	3,5
Neuroimaging with EEG, fNIRS and fMRI	2
Imaging Laboratory	3
Inverse Problems in Medical Imaging	5
Machine Learning	5
Principles of Brain-Computation	5
Computational Intelligence Seminar A	3,5
Computational Intelligence Seminar B	3,5
Neural Networks	5
Network Science	5
Seminar/Project Machine Learning & Neuroinformatics / Brain-Computer Interfacing	6
Neural Engineering	
Selected Topics Neural Engineering	3
Medical Instrumentation	3
Interdisciplinary Team-taught Lecture Series: Trends in Neurorehabilitation	3
Rehabilitation Engineering	3
Neuroprosthetics	5
Biological Control, Modeling and Simulation	6
Elective module Health Care Engineering	**Major: Biomedical Device Design & Safety** **Minor 1: Clinical Engineering** **Minor 2: Cellular Electrophysiology and Sensors**
Prerequisites	
Hospital utility management	3
Biomedical Device Design & Safety	
Medical devices technology	3
Medical devices safety / Lab	3
Foundations of quality management in medicine	3
Medical device act / regulations	3
Biomedical Sensor Systems 2	2
Practical Analog Circuit Design	3
Practical Analog Circuit Design, Laboratory	1.5
EMC of Electronic Systems	3
Foundations of electrical drives	2
Control of Medical Instrumentation	3
Development of Electronic Systems	6
MB-basic training HCE 1	4
CAD	3
CAE	2
Foundations in quality management in medicine	1.5
Medical devices technology	3
EMC of Electronic Systems, Laboratory	2
Foundations in high frequency engineering	5
Energy technologies for biomedical	3
Microcontroller	2
Clinical Engineering	
Foundations in Hygiene and Microbiology	3
Predictive Healthcare Information Systems	3
Hospital technology / Lab	3
Health care systems and health care economics	3
Hospital project management	3
Rehabilitation Engineering	3

Health Care Engineering, Project	3
Medical Laser Technology	3
Radiation protection in medicine	3
Cellular Electrophysiology and Sensors	
Cellular Electrophysiology and Models	3
Cellular Electrophysiology and Models, Laboratory	1.5
Biomedical Sensor Systems, Laboratory	3
Basics of Microelectronics	3
Chemical Analytics and Sensors	4.5
Sensor Networks	3
Medical Instrumentation	3
Biosignal Processing	3
Molecular Diagnostics	5
SC Computational Bioengineering	3
Elective module Business, Law, Management and Soft Skills	**Minor**
Encyclopedia Business Economics	7,5
Financial Management	3
Management Control Systems	4,5
Rhetoric und Presentation	2
Purchasing and Supply Management	4,5
Marketing Management	3
Research Design in Management Science	2
Financial accounting	2,5
Profit and loss account	3,5
Civil law and corporate law	3
Labour law	3
Patent law	3
Tax law	3
Marketing Intelligence	1
Industrial sociology	3
AK Controlling	4

Name of HEI and programme	**Degree awarded**	**Credits**	**Duration of study**
Technical University Vienna **Master in biomedical engineering**	**Dipl.Ing. / MSc**	**120**	**4 semesters**
Courses		**Credits**	
Life Sciences		**15**	
Biology		3	
Microscopy in biology		3	
Anatomy and histology		4,5	
Physiology and basics of pathology		4,5	
Core Biomedical Engineering		**24**	
Introduction to biophysics		3	
Introduction to biomechanics		3	
Biomedical sensors and signals		3	
Biomedical instrumentation		3	
Introduction to Biological Chemistry		3	
Instrumental Analytical Biochemistry		3	
Biostatistics		3	
Medical Image Processing		3	
Biocompatible Materials		3	
Introduction to Biomaterials and Tissue Engineering		3	
Molecular Biology of the Cell		3	
Biomembranes		1,5	
Mathematical Systems Biology		1,5	
Electives Basics / Advanced		**42**	
Basics		15	
Advanced		9	
Project		6	
Optional electives		12	
Elective Biomaterials & Biomechanics			
Basics of Biomaterials & Biomechanics		**15**	
Biomaterials		3	
Computational Biomaterials and Biomechanics		3	

Modelling of the Human Locomotor System	3
Tissue Biomechanics	3
Waves, Imaging and Fluid-Structure Interactions in Medicine and Biology	3
Advances in Biomaterials & Biomechanics	9
Basics of Lung Physiology and Ventilation Technique in Medicine	1,5
Biomechanics of the Human Locomotor System	3
Cardiovascular System Dynamics	1,5
Engineering Biochemoporomechanics	5
Experimental Determination of Mechanical Properties of Biological Tissues	2
Finite Element Methods in Biomechanics	5
Fracture Mechanics	2
Injury Mechanics	2
Laboratory Course the Motor Muscl	3
Material Characterization	3
Prosthetics	3
Mechanical Properties of Biological Tissue	3
Seminar of Biofluid Mechanics	3
Rehabilitation Engineering	3
The Motor Muscle	3
Tissue Biomechanics	7
Multiscale Material Modelling	5
Waves, Imaging and Fluid-Structure Interactions in Medicine and Biology	2
Mechanical Properties of Biological Tissue	2
Experimental Determination of the Mechanical Properties of Biological Tissues	2
Experimental Mechanics and Characterization of the Hierarchical Structure of Biological Tissues	3
Additive Manufacturing Technologies	2
Project Biomaterials & Biomechanics	**6**
Elective Biomedical Signals & Instrumentation	
Basics of Biomedical Signals & Instrumentation	**15**
Biomedical Mass Spectrometry	3
Biochip Technologies in (Bio)Analytical Chemistry	3
Sensors and Microsystem Technology	3
Laser in Physics, Chemistry, Biology and Medicine	3
Microelectronic Concepts for Biomedical Interfacing	3
Advances in Biomedical Signals & Instrumentation	**9**
Applied Vibrational Spectroscopy	3
Biomedical Sensors and Signals	2
Selected Topics - Biophysics	5
Biosensors and Bioprocess Analytics	1,5
Chemical Nanoscopy	3
Industrial Proteomics	3
Medical Computer Vision	3
Medical Laser Optics	2
Process technologies for microelectronic, photonic and microsystem devices	3
Rehabilitation Engineering	2
Technical Restoration of Body Functions by Means of FES	3
Functional Electrostimulation: theory and practice 1	4,5
Functional Electrostimulation: theory and practice 2	4,5
Selected Topics - Microelectronic Concepts for Biomedical Interfacing	3
Microlectrodes & Microfluidics for Biomedical Applications	4,5
Sample Preparation and Basic Concepts in Bio	2
Assistive Technologies 1	3
Assistive Technologies 2	3
Medical Image Processing	3
Project Biomedical Engineering	**6**
Elective Mathematical and Computational Biology	
Basics of Mathematical & Computational Biology	**15**
Bioinformatics for Biomedical Engineers	3
Computational Biomaterials and Biomechanics	3
Computer Simulation in Medicine	3
Neuron Modeling	3
Control Models in Physiology	3
Advances in Mathematical & Computational Biology	**9**

Mathematical Systems Biology	1,5
Biometry and Epidemiology	3
Brain Modelling	3
Computer Simulation in Medicine	3
Diagnoses and Treatment Planning	6
Computer Training in Biomathematics	3
Epidemiology	3
Finite Element Methods	4,5
Hearing Theory	3
Identification/experimental modelling	3
Mathematical Models of Drug use and Drug Control	3
Modelling and Simulation of the Heart Circulation	3
Machine Learning for Visual Computing	4,5
Research Seminar on Computer Graphics	3
Stationary Processes and Time Series Analysis	4,5
Project Biomedical Engineering	**6**
Medical Physics & Imaging	
Basics of Medical Physics & Imaging	**15**
Biological and Medical Applications of Nuclear Physics I	3
Microscopy of Biomolecules	3
Medical Physics of Diagnostic Imaging	3
Ultrasound in Nature, Engineering and Medicine	3
Computerunterstützte Abbildungsverfahren	3
Advances of Medical Physics & Imaging	**9**
Microscopy of Biomolecules	2
Single Molecule Microscopy	2
Application of Radiation Physics in Engineering and Medicine	2
Biological and Medical Applications of Nuclear Physics II	3
Selected Topics - Biophysics	5
Computer Graphics	3
Introduction to Biophysics	3
Introduction to Digital Image Processing	2
Introduction to Pattern Recognition	3
Laser in Physics, Chemistry, Biology and Medicine	3
Medical Image Processing	3
Radiation Physics	4,5
Radiation Protection and Dosimetry	3
3D Vision	5
Statistical Pattern Recognition	
Visualization of Medical Data 2	3
Functional Imaging Technology and Devices - Physical Principles	3
Application of ionizing radiation in medicine	3
Molecular Biophysics	4,5
Interferometry and non-linear optics in medical imaging	3
Project Biomedical Engineering	**6**
Free electives and soft skills	**9**
Master's thesis	**30**

Selected curricula of relevant programmes at bachelor's level in Germany

The list comprises a representative selection of two bachelor's study programmes – one organised at a traditional and one organised at a University of Applied Sciences.[11]

Name of HEI and programme	Degree awarded	Credits	Duration of study
HAW Hamburg **Bachelor in biomedical engineering**	**BSc**	**210 ECTS**	**7 semesters**
Courses		**Credits**	
Semester 1		**30**	
Mathematics 1		7	
Informatics 1 Lab		3	
Physics 1		5	
Chemistry		5	
Cell and microbiology		5	
Hygiene		2	
Communication and presentation		2	
Semester 2		**30**	
Mathematics 2		4	
Informatics 2		2	
Physics 2		2	
Hygiene lab		3	
Project management		3	
Technical mechanics 1		5	
Statistics		2	
Engineering science		2	
Electrical engineering 1		5	
Electronics 1 / Lab		2	
Semester 3		**30**	
Mathematics 3		3	
Physics lab		3	
Electrical engineering 2		5	
Electronics 1		5	
Informatics 3		2	
Informatics 3 lab		3	
Thermodynamics		3	
Human biology 1		4	
Semester 4		**30**	
Fluid dynamics		2	
Human biology 2		4	
Electronics 2		5	
Electronics 2 lab		2	
Signal processing and systems theory		4	
Mathematics 4		3	
Signal processing and systems theory / Lab		2	
Business administration		2	
Cost accounting		2	
Marketing & sales		2	
Measurement technology		5	
Semester 5			
Measurement technology practical course		2	
Control engineering		5	
Control engineering practical course		2	
Medical software technology		3	
Medical software technology practical course		2	
Health care law		2	
Quality management		3	
Medical measurement technology and instrument engineering		5	
Electives according to specialistion track		5	
Semester 6			
Internship		28	

[11] https://www.haw-hamburg.de/bachelor-medizintechnik.html , https://www.tu-chemnitz.de/etit/studium/stugang/B_Biomedizine/index.php Accessed 20.03.2018

Internship seminar	3
Semester 7	
Imaging methods in medicine	6
Medical measurement technology and instrument engineering / practical course	3
Human biology / practical course	3
Electives according to specialisation track	5
Bachelor's thesis	12
Electives semester 5 and semester 7	**30**
Specialisation Measurement technology and instrument engineering	15
Microprocessor technology	5
Mikroprozessor practical course	5
Computer based Messdatenerfassung	2,5
Radiation technology	2,5
Nuclear medicine technology	2,5
Medical laser techniques	2,5
Ultrasound therapies	2,5
Regulatory affairs	2,5
Polymere electronics	5
Study project	5
Specialisation biomechanics	
Biomechanics	5
Technical mechanics 2	2,5
Orthopaedic implantology and endoprosthetics	2,5
Construction / CAD	2,5
Construction / CAD practical course	5
Study project	5
Specialisation medical informatics	
Microprocessor technology	5
Microprocessor / practical course	2,5
Computer-based collection of measurement data	2,5
Foundations medical image processing	2,5
Medical data visualisation	2,5
Foundations medical signal processing	2,5
Advanced data base use	2,5
Data networks: technology and programming	2,5
Study project	5

Name of HEI and programme	**Degree awarded**	**Credits**	**Duration of study**
TU Chemnitz **Bachelor in biomedical engineering**	**BSc**	**180**	**6 semesters**

Courses	**Credits**
Basic modules	**78**
Mathematics 1	8
Mathematics 2	8
Mathematics 3	5
Foundations electrical engineering	18
Foundations informatics I	5
Foundations informatics II	5
Data structure	8
Basics in anatomy and physiology	8
Materials in electrical engineering / electronics	3
Technical physics	5
Technical mechanics 1	5
Electives electrical engineering	**27**
Micro and precision engineering	5
Micro- and nanosystems	3
Electric circuit technology 1A	6
Medical devices technology	5
Technical reliability	3
Electrical measurement technology	5
Electives in informatics	**23**
Foundations of technical informatics	8
Computer networks	5

IT-security technology	5
Computer organisation	5
Electives medicine	**11**
Health care system / evidence based medicine	3
Medical technology applications A	5
Medical basics - internal diseases	3
Advanced courses	**26**
Electrical circuit technology 2B	4
Microtechnologies	5
Micromechanic components	3
Systems theory	5
CAD	5
Data base foundations	5
Distributed software security	5
Distributed software architecture	5
Image understanding and analysis	5
Computer graphics I	5
Introduction to artificial intelligence	5
IPR	3
Biopsychology	4
Advances in medical technology	3
Medical basics of orhtopaedics / traumatology	3
Basics bio mechanics and exercise science	2
Basics sports medicine	3
Internship	10
Bachelor thesis	**15**

Selected curricula of relevant programmes at master's level in Germany

The list shows a representative selection of two masters's study programmes - one organised at a traditional university and one organised at a University of Applied Sciences.[12]

Name of HEI and programme	**Degree awarded**	**Credits**	**Duration of study**
FH Aachen University of Applied Sciences **Master of biomedical engineering**	**MSc**	**120**	**4 semesters**
Courses		**Credits**	
Summer semester		**30**	
Integrative adjustment modules			
Anatomy		5	
Physiology		5	
Cell biology		5	
Chemistry/biochemistry		5	
Electrical engineering		5	
Fluid dynamics		5	
Mechanics		5	
Medical Measurement		5	
Written project 1-5		max. 25	
Mobility period		max. 25	
Winter semester		**30**	
Fluid dynamics		5	
Written project 1-5		max. 25	
Mobility period		max. 25	
Summer semester		**30**	
Electives			
Artifical organs		5	
Biomaterials / biocompatibilty		5	
Biomechanics		2,5	

[12] https://www.fh-aachen.de/studium/biomedical-engineering-msc/ , https://www.uni-heidelberg.de/studium/interesse/faecher/biomed-eng.html Accessed 07.03.2018

Cellular and molecular biophysics	5
Dynamic systems and computer modelling	5
Engineering and bioactive surfaces	5
Finite element method	5
Integrated circuit design	5
Laser applications in medicine and biology	2,5
Laser technology	2,5
Molecular biology and genetics	2,5
Winter semester	**30**
Electives	
Artifical organs 1	5
Biosensors/chemical sensors	5
Cardivascular mechanics	2,5
Extracorporal fluid mechanics	2,5
Cellular and molecular biophysics	5
German	5
Material science and biocompatibility	5
Medical imaging	5
Medical statistics	5
Medical physics and medical imaging technology	5
Research planning and scientific writing	5
Optional courses	
Cell culture technology (basics)	2,5
Radiation	2,5
Microscopy	2,5
Cell culture techniques	2,5
Biomedical applications of nuclear technology	2,5
Introduction to information processing 2	5
Electrophysiology, electromedicine	5
Continuum mechanics	5
German (advanced level)	5
Regenerative medicine	5

Name of HEI and programme	**Degree awarded**	**Credits**	**Duration of study**
University of Heidelberg **Master in biomedical engineering**	**MSc**	**120**	**4 semesters**

Courses	**Credits**
Semester 1	**30**
Biophysics	8
Engineering Mathematics + Exercises	8
Basic Molecular and Cellular	5
Biology Basic Medical Science	18
Radiation Physics and Instrumentation	5
Radiation Protection	5
Radiotherapy Treatment Planning/Quality Assurance	8
Treatment Planning and Quality Assurance Lab	3
Image Guided Radiotherapy	5
Physics of Imaging Systems	5
Biomedical Optics	5
Biomedical Engineering + Exercise Basic Optics and Laser	3
MR-Radiology Lab	5
Seminar: MR Methods and Technology	3
Image Analysis + Exercises	
Matlab Programming	
Semester 2	**30**
Radiobiology	8
Basic Cellular Biology/Radiobiology Lab Seminar	5
Seminar Radiobiology	5
Special Radiotherapy Techniques	5
Lab Medical Physics in Imaging	3
Seminar: Physics of Advanced MRI/CT Techniques	5
Simulators in Games and Medicine + Exercises	3
Volume Visualization + Exercises (advanced)	**26**
Inverse Problems + Exercises (advanced)	4
Computational Medial Physics Lab (advanced)	5
Semester 3	3

Treatment Planning and Quality Assurance Lab	5
Image Guided Radiotherapy	5
Biomedical Optics	5
Biomedical Engineering + Exercise	5
Seminar: MR Methods and Technology	5
Advanced Imaging Techniques	5
Medical Devices and Imaging Systems	5
MRT Basics	5
X-Ray Diagnostics and Sonography	3
Image Analysis + Exercises	4
Matab	3
General Science Skills	3
Specialized Lab Project	2
Semester 3 Electives	30
Neurosciences	**max. 30**
Nanotechnology	3
BioMEMS	3
Biomaterials	3
Neurobiology	3
Structure & Function of Biomacromolecules	4,5
Theoretical Neurosciences	4,5
Experiments of modern lab animal science	1,5
Bioheat & Mass Transfer	4,5
Neuroinformatics	3
Imaging / biomedical optics	**max. 30**
Physical therapy technology	4,5
Biomedical ultrasound	4,5
Medical imaging	3,75
New Technology in Medical Imaging	3
Biomedical Sensors	4,5
Laser medicine & biophotonics	3
Frontier problems of optics	4,5
Non-linear optics of optical fibers	4,5
Modern optics	4,5
Optoelectronics	3
Semiconductor devices	3
Processing of optical information	3
Principle & technology of laser	4,5
Non-linear optics	4,5
Engineering optics	4,5
Computer engineering	**max. 30**
Application of Computers in Life Sciences	3
Signal processing	4,5
Digital signal processing	3
Bioinformatics	3
3D image processing & volume visualization	3
Adaptive filtration	3
Biomedical image processing	4,5
TMS320 digital signal processor	3,75
Random signal processing	4,5
Opt. estimation theory & system identification	4,5
Computer graphics	4,5
Wireless communication & sensor networks	3
Mobile & wireless networking	4,5
Semester 4	
Master's thesis	**30**

Co-funded by the
Erasmus+ Programme
of the European Union

Selected curricula of relevant programmes at bachelor's level in Switzerland

This list shows two bachelor's study programmes – one organised at a traditional university and one organised at a University of Applied Sciences.[13]

Name of HEI and programme	Degree awarded	Credits	Duration of study
Luzern University of Applied Sciences and Arts **Bachelor in medical engineering**	**BSc**	**180**	**6 semesters**
Courses		**Credits**	
Semester 1			
Compuslory			
Mathematics fundamentals		6	
Software engineering		3	
Computer science fundamentals		6	
Cell biology		3	
Chemistry		3	
Context 1		6	
Electives			
Stochastics		3	
Energies, fluids and processes / Lab 1		3	
Treatment Planning and Quality Assurance Lab		3	
Industrial design		3	
Semester 2			
Compulsory			
Mathematics and physics technology 1		6	
Electrical engineering with lab		3	
Mechanics and materials science		3	
Human anatomy and physiology 1 (with lab)		6	
Quality management and admission		3	
Context 2		3	
Electives			
Lean management (intensive week)		3	
Engineering tools		3	
Quantitative data analysis		3	
Energies, fluids and processes lab 2		3	
Semester 3			
Compulsory			
Mathematics and physics technology 2		6	
Mechanics and materials science II		3	
CAD		3	
Medical device development fundamentals		6	
Engineering product development project 1		3	
Electives			
Human anatomy and physiology 2 (with lab)		3	
Measurement technologies and sensors		3	
Nanotechnology (intensive week)		3	
Microtechnology		3	
Semester 4			
Compulsory			
Usability and risk management		6	
Medical engineering project		3	
Engineering product development project 2		6	
Electives			
Embedded systems		6	
Mechanical design and construction		6	
Medical journal club		3	
Technical optics		3	
Physics lab		3	
Materials lab (intensive week)		3	
Semester 5			
Compulsory			

[13] https://www.zhaw.ch/en/engineering/study/bachelors-degree-programmes/systems-engineering/ , https://www.hslu.ch/en/lucerne-school-of-engineering-architecture/degree-programmes/bachelor/medizintechnik/ Accessed 17.04.2018

Biomechanics	3
Biocompatibility and sterilisation processes	3
Product management and marketing for medical devices	3
Medical device production	3
Industrial project	6
Medical imaging	3
Electives	
Practical studies	3
Interdisciplinary innovation workshop engineering	3
Advanced mathematics	3
Medical software and information technologies in hospitals	3
Semester 6	
Compulsory	
Biosignal processing and measurement technologies	3
Medical language, culture and ethics	3
Bachelor's thesis	12
Electives	
Applied modern physics and mathematics	3
Microfabrication	3

Name of HEI and programme	**Degree awarded**	**Credits**	**Duration of study**
Zurich University of Applied Sciences (ZHAW) **Bachelor in systems engineering / specialisation medical technology**	**BSc**	**180**	**6 semesters**

Courses	**Credits**
Semester 1	**30**
Communication competence scenario - Booster	2
Communication competence scenario - Starter	2
Product development and systems engineering 1	4
Mechanics for systems engineering 1	2
Electrical and measurement engineering basics 1	2
MATLAB	2
Digital technology	2
Informatics for engineers 1	4
Mathematics: analysis for engineers 1	3
Mathematics: linear algebra for engineers 1	3
Physics 1	4
Semester 2	**30**
Communication competence scenario - Starter	2
Product development and systems engineering 2	4
Mechanics for systems engineering 2	2
Electrical and measurement engineering basics 2	2
Materials engineering	2
Electronic engineering	4
Informatics for engineers	4
Mathematics: analysis for engineers 2	3
Mathematics: linear algebra for engineers 2	3
Physics for systems technology 2	4
Semester 3	**30**
Communication competence scenario - Academic	2
Business and economics for engineers	2
Product development for systems engineering 3	4
Mechanics for systems engineering 3	4
Electricity 3	4
Signals and systems 1	4
Computer technology 1	4
Mathematics: numeric and differential equation 1	3
Mathematics: analysis and stochasics 1	3
Semester 4	**30**
Communication competence scenario - Business	2
Product development for systems engineering 4	4
Mechanics for systems engineering 4	2
Electricity 4	4
Control engineering	4
Computer technology 2	4
Mathematics: numeric and differential equation 2	3
Mathematics: analysis and stochasics 2	3

Physics: fields and waves	4
Semester 5	**30**
Elective module	2
Elective module economics and law	2
Systems engineering proejct	6
Anatomy, physiology and biophysics	4
Medical technology 1	4
Elective module medical technology	4
Elective module	4
Elective module	4
Semester 6	**30**
Human, technology and environment	2
Bachelor's thesis in systems engineering	12
Medical technology 2	4
Selected topics in medical technology	4
Elective module	4
Elective module	4

Selected curricula of relevant programmes at master's level in Switzerland

The following list shows two master's degree programmes – one organised at a traditional university and one organised at a University of Applied Sciences.[14]

Name of HEI and programme	**Degree awarded**	**Credits**	**Duration of study**
University of Bern **Master in biomedical engineering**	**MSc**	**120**	**4 semesters**
Courses		**Credits**	
Semester 1			
Basic modules		**28**	
Numerical Methods		5	
Basics in Physiology for Biomedical Engineering		3	
Biological Principles of Human Medicine		3	
Introductory Anatomy and Histology for Biomedical Engineers		3	
Biomedical Instrumentation		5	
Engineering Mechanics		6	
Principles of Medical Imaging		3	
Preparation Courses (Elective Courses in all Major Modules)			
Introduction to Electrical Engineering		2	
Introduction to Programming		2	
Selected Chapters in Mathematics		2	
Short Introduction to MATLAB		1	
Semester 2			
Basic modules		**8**	
Introduction to medical statistics		3	
Biomaterials		5	
Complementary Skills - Mandatory courses		**6**	
Regulatory affairs and patents		4	
Complementary Skills – Elective courses		**2-6**	
Clinical epidemology and health technology assessment		2	
Biomechanical Systems - Mandatory Courses		**16**	
Continuum mechanics		3	
Finite element analysis 1		3	
Fluid mechanics		4	
Biomechanical Systems - Elective Courses		**26-30**	
Dynamical Models: Analysis, Conception and Simulation		3	
Measurement Technologies in Biomechanics		3	
Microsystems Engineering		3	
Regenerative Dentistry for Biomedical Engineering		2	

[14] https://master.epfl.ch/bioengineering , http://www.bme.master.unibe.ch Accessed 17.04.2018

Electronic Implants - Mandatory Courses	**16**
Biomedical Signal Processing and Analysis	3
Low Power Microelectronics	4
Microsystems Engineering	3
Wireless Communication for Medical Devices	3
Electronic Implants - Elective Courses	**26-30**
Biomedical sensors	3
C++ Programming I	3
Dynamical Models: Analysis, Conception and Simulation	3
Finite Element Analysis I	3
Introduction to digital logic	3
Image-Guided Therapy - Mandatory Courses	**16**
Computer-Assisted Surgery	3
Introduction to Signal and Image Processing	5
Medical Robotics	3
Image-Guided Therapy - Elective Courses	**26-30**
Advanced Topics in Machine Learning.	5
C++ Programming I	3
Dynamical Models: Analysis, Conception and Simulation	3
Finite Element Analysis I	3
Image-Guided Therapy Lab	3
Microsystems Engineering	3
Semester 2	
Complementary skills – mandatory courses	**6**
Innovation management	2
Complementary skills – elective courses	**2-6**
Ethics in Biomedical Engineering	2
Scientific Writing in Biomedical Engineering	2
Biomechanical Systems - Mandatory Courses	**16**
Tissue Biomechanics	3
Tissue Engineering	3
Major Module Biomechanical Systems - Elective Courses	**26-30**
Applied Biomaterials	3
Basics of Applied Molecular Biology	1
BioMicrofluidics (2 ECTS)	2
Cardiovascular Technology	3
Cutting Edge Microscopy	3
Design of Biomechanical Systems	3
Finite Element Analysis II	3
Functional Anatomy of the Locomotor Apparatus	3
Intelligent Implants and Surgical Instruments	3
Molecular and Cellular Biology Practical	2
Orthopaedic Surgery – Practical Course	2
Osteology	3
Rehabilitation Technology	3
Tissue Biomechanics Lab	2
Tissue Engineering – Practical Course	2
Electronic Implants - Mandatory Courses	**16**
Intelligent Implants and Surgical Instruments	3
Electronic Implants - Elective Courses	**26-30**
Applied Biomaterials	3
Biomedical Acoustics	3
Biomedical Laser Applications	4
BioMicrofluidics	2
Cardiovascular Technology	3
C++ Programming II	3
Finite Element Analysis II	3
Programming of Microcontrollers	5
Rehabilitation Technology	3
Technology and Diabetes Management	3
Image-Guided Therapy - Mandatory Courses	**16**
Medical Image Analysis	5
Image-Guided Therapy - Elective Courses	**26-30**
Clinical Applications of Image-Guided Therapy	3
Computer Graphics (German)	5
Computer Vision	5
C++ Programming II	3
Finite Element Analysis II	3
Functional Anatomy of the Locomotor Apparatus	3
Intelligent Implants and Surgical Instruments	3

Machine Learning	5
Medical Image Analysis Lab	4
Ophthalmic Technologies	3
Programming of Microcontrollers	5
Semester 4	
Master's thesis	**30**

Name of HEI and programme	**Degree awarded**	**Credits**	**Duration of study**
Ecole Polytechnique Federale De Lausanne **Master in bioengineering**	**MSc**	**120**	**4 semesters**

Courses	**Credits**
General bioengineering	**12**
Analysis and Modelling of Locomotion	3
Biomicroscopy I	3
Fundamentals of Neuroengineering	4
Materials Science	3
Principles and Applications of Systems Biology	3
Stem Cell Biology and Technology	3
Scientific thinking	**5**
Scientific literature analysis in bioengineering	5
Scientific project design in cell and developmental biology	5
Scientific literature analysis in computational molecular biology	5
Scientific literature analysis in molecular and cancer biology	5
Scientific literature analysis in Neuroscience	5
Scientific project design in Drug Discovery	5
Scientific project design in regenerative medicine and diagnostics	5
Scientific project design in Synthetic Biology (iGEM)	5
Scientific project design in Translational Neurosciences	5
Scientific project design in Translational Oncology	5
Orientations and options	**59**
Regenerative medicine	
Biomaterials	3
BioMEMS	2
Biomicroscopy II	4
Genomics and Bioinformatics	4
Sensory in medical instrumentation	3
Tissue engineering	4
Biomechanical engineering	
Biomaterials	3
Biomechanics of the Cardiovascular System	3
Biomechanics of the Musculoskeletal System	5
Computational Motor Control	4
Numerical methods in biomechanics	3
Sensors in medical instrumentation	3
Sensorimotor Neuroprosthetics	4
Systems bioengineering	
Biomolecular Structure and Mechanics	4
Dynamical System Theory for engineers	4
Genomics and Bioinformatics	4
Modèles stochastiques pour les communications	6
Statistical Physics of Biomacromolecules	4
Stochastic models in communication	6
Nanoscale bioengineering	
Advanced Bioengineering Methods Laboratory	4
Biomolecular Structure and Mechanics	4
Chemical Biology - Tools and Methods	3
Fundamentals of biosensors and electronic biochips	3
Statistical Physics of Biomacromolecules	4
Biophotonics and bioimaging	
Biomicroscopy II	4
Dynamical System Theory for engineers	4
Fundamentals of Biomedical Imaging	4
Fundamentals of Biophotonics	3
Image analysis and pattern recognition	4
Image Processing I, II	6

Signal Processing for Functional Brain Imaging	3
Law, Organization and Economics in LST	
Economics of innovation in the biomedical industry	3
Introduction au droit et à l'éthique en STV	3
Lab methods: Biosafety	3
Multidisciplinary organization of medtechs/biotechs	3
Other accredited courses	**max. 10**
Analog circuit for biochip	3
Applied biostatistics	4
Applied data analysis	6
Applied probability and stochastic processes	4
Bioinspired approaches to engineering	2
Biomedical Optics	**3**
Biomedical signal processing	6
Biophysics I, II	6
Brain Computer interaction	3
Data Analysis and Model Classification	**4**
Flexible bioelectronics	3
Introduction à l'informatique visuelle	4
Introduction to nanomaterials	4
Lab Immersion I	8
Lab Immersion II	8
Lab Immersion III (semester project)	12
Lab immersion academic (outside EPFL) A and B	22
Lab immersion in industry A and B	22
Lab methods: Animal Experimentation	2
Lab methods: Bioactive compounds screening	2
Lab methods: Flow Cytometry	2
Lab methods: Histology	2
Lab methods: Proteomics	2
Mécanique des structures	4
Nanobiotechnology in biophysics	3
New tools and research strategies in personalized health	4
Pharmacology and Pharmacokinetics	5
Seminar in physiology and instrumentation	2
Single cell genomics	4
Technologie des microstructures I	3
Understanding statistics and experimental design	4
Master's thesis	**30**

4. Comparative curricula analysis - synopsis

As the field of biomedical engineering matures, education at the bachelor's level is being formalised in the universities of applied sciences as well as many traditional universities across the German-speaking region. The curriculum analysis shows, that higher education institutions and their respective departments are striving to find the perfect balance of courses that expose the students to a wide range of topics that span the breadth of science, medicine and engineering.
A comparative approach reveals further that different strategies are applied, each with its own advantage: whereas the traditional universities focus on paving the road for research thus desiging their curricula towards advanced degrees and graduate–level research, the majority of universities of applied sciences' curricula require internships, which not only allow the students to experience corporate culture but may turn into full–time jobs. Other universities have developed specilisation tracks that are perfect for students who have a passion for a certain field of study but are perhaps not yet ready for an advanced degree such as PhD.

Although promoted under the same name, the various biomedical engineering study programmes at undergraduate and (post)-graduate level offered by the presented universities, differ greatly from each other. The universities' strength of research in the respective biomedical engingeering areas is certainly reflected by the courses they offer in their programmes and the emphasis of the individual study programmes.

Given the diversity of scientific fields and study programmes that are presented here, the curricula reveal a shared structure: undergraduate studies start with obligatory basic subjects such as mathematics and an introduction to mechanical and electrical engineering. In the second year, special subjects (as in elective courses) can be chosen optionally out of the ones announced in the curriculum, in a prescribed obligatory number of hours or credits. Further on, common training and specialisation according to the speclisation track will be carried out. The main set of teaching objectives that can be derived from this curricula analysis is a core set of knowledge and skills integrating disciplines related to

- Engineering science, such as mechanical, electrical, electronics and computer engineering, as well as
- Physical, mathematical and life sciences for the
- Application of technology in the health sector, from basic biological and medical

research to clinical practice.

All curricula are supported with topics such as equipment quality control and quality assurance, basic research methodology, data collection and analysis, report writing techniques, and at the universities of applied sciences, practical constructions and the application of acquired knowledge in real working environments.

Study programmes at master's level share a similar structure with regard to extensive research projects leading to a thesis examination. Building on an indispensable core knowledge in engineering, physical and life sciences, these pogrammes proceed to the teaching of applied material, mainly in the following biomedical engineering specialisation areas: in-vivo and in-vitro diagnostic systems, advanced biomaterials and biomechanics, advanced medical imaging systems, ICU technologies, advanced digital signal and image processing, theoretical principles of operation and technological applications of therapeutic systems (e.g. radiotherapy and electrotherapy systems), rehab engineering and clinical engineering, regenerative medicine and artificial organs.

Rapid developments in technology as applied in medicine will continue to change what biomedical engineers do and continue to generate new areas for them to work in. A higher education programme must therefore aim at producing biomedical engineers who are skilled professionals with significant expertise in engineering technology and adequate exposure to medical sciences. For a university without a medical faculty, there can be difficulties for developing bio(medical) engineering study programmes. However, some of the here presented programmes show that these difficulties can be overcome if sufficient support is provided by the university and sources outside the university (e.g. collaborative partnership with a medical university).

Driven by continuous research advances, leading to new equipment and techniques, the field of biomedical engineering is in the process of an astounding evolution characterised by an increasing degree of diversification. The German Ministry of Education and Research identified the following as the currently most intensively researched areas and topics in biomedical engineering:

- Cell and tissue engineering
- Therapeutic systems
- Diagnostic systems
- Technology and systems supporting minimal invasive interventions

- Laboratory technology
- Surgical technology and devices/systems
- Ophthalmologic devices and systems
- Hospital technology
- Physiotherapy devices
- Rehabilitation devices and systems
- Audiologic devices and systems
- Dental devices and systems

With an emphasis on:

- Medical imaging
- E-Health, software and Telemedicine
- Prosthetics and implants

What this comparative analysis also shows, is that although originally biomedical engineering programmes were integrated into the traditional engineering education in the curriculum, there is an increase in the number of programmes, completely independent from traditional engineering training. Furthermore there is an increasing number of adopted courses such as technology management, business and economics, professional ethics, creative thinking, understanding of cultural, social, economic and political impact of technology.

What is indeed necessary when rethinking a curriculum structure and content, is the choice of the basic structure of activities and the desired competence level, which in turn will establish the goals of the curriculum and the level at which these goals are set should be a compromise between the resources utilised and the outcomes produced. It must be stressed that in order to meet the stringent academic requirements imposed on a biomedical engineer, the study period is usually very demanding. This in turn results in an extensive workload for the students.

An interpretation of the current developments and predicition of future trends suggest that the dynamic labour markets and corresponding constantly changing work environments require transferable competences in professionals. The idea of anchoring transferable skills in syllabi is already being adopted by universities and programme directors and will certainly further shape higher education curricula.