Study regulations of the Master study program

Bio-Inspired Engineering

Leading to the award of the academic title

Master of Science in Engineering
(MSc.)

as an appendix to the statutes of the FH Kufstein Tirol

Organizational form: part-time
Duration: 4 semesters
Number of ECTS 120 ECTS
Number of places per academic year: 15

Version 1
Generated by transferring the content of the accreditation application
“2_Master-Lehrgang BIE Stand 23012017”
Approved by the FH Kufstein Board on 1 February 2017

Content

1 JOB PROFILES

1.1 Fields of employment

General information

As already described, a fundamental understanding of biological processes is essential for biomimetics. Biomimetics is a highly interdisciplinary field of science. Developing innovative technical products and processes inspired by the natural world generally takes place through several steps of abstraction and modification. In bionic research and development it is possible to differentiate between two main approaches: bottom-up and top-down. The bottom-up approach (also known as "biology push") stands for processes where interesting discoveries in the natural world serve as an inspiration for products and processes. The top-down approach (also known as "biology pull") refers to a scenario where researchers and scientists set out to achieve a specific bionic improvement.

Core fields of biomimetics

The following core fields can be identified in which students of biomimetics are able to work following graduation (in alphabetical order):

- Architecture and design offices
- Chemical and pharmaceutical industry
- Electronics and electrical engineering companies
- Renewable energies
- Vehicle manufacturing industry
- Wood construction and architecture
- Consumer goods and industrial goods production
- Aircraft and aerospace industry
- Machinery and plant engineering
- Process automation and optimization
- Rehabilitation and medical technologies
- Automation technologies
- System manufacturers
- Traffic and transport

Details on potential areas of work

In the guidelines of the Association of German Engineers (VDI) the bionic working process is described as follows (VDI, 2012):

Brainstorming → Analysis → Abstraction & Analogy → Planning to Innovation → Communication Process → Integration in Innovation Process (2012). Most areas in which bionic working is used have this process and its individual steps in common. The lexicon of the Public Employment Service Austria (AMS) describes the profession of a bionics expert as follows[1]. The potential areas of work are highly interdisciplinary. Bionics experts work in close cooperation with biologists, zoologists, engineers, architects, physicists, chemists, material researchers and designers. They look at how to creatively adapt aspects of the natural world for use in technical applications. For this they carry out research into biological systems, processes and structures in plants and animals. Furthermore, they use biological principles and phenomena in order to come up with innovative solutions to technical problems. While **biotechnology** uses plants and animals to either produce or eliminate certain substances, in bionics plants and animals are the providers of ideas (Brandau, 2014).

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[1] Source: http://www.berufslexikon.at/beruf2995

Below is (in alphabetical order) a list of fields in which bionics experts may find work:

Applied research and development

Research and development is the systematic search for new knowledge using scientific methods in a planned way. While *research* refers to the general acquisition of new knowledge, *development* focuses on using this knowledge for the first time in concrete, practical situations (Springer Gabler Verlag).

Therefore, biomimetics is in many ways the ultimate field of R&D. Biomimetics – learning from nature and applying this knowledge to our modern-day world – requires us to observe and analyze the natural world using scientific methods as well as to evaluate this knowledge using computer technology and to transfer it to the world around us by coming up with a solution to a problem. Furthermore, biomimetics can also be used in basic research for new approaches such as self-assembly and digital materials.

There is a wide range of research topics which are dealt with using biomimetics; they can be divided into three main groups:

- Construction or structure bionics (surfaces, constructions)
- Process bionics (e.g. photosynthesis) and
- Information bionics (e.g. evolution)

Bionics can be applied in particular to the fields of medicine, surface technologies, mechanical engineering, material development, architecture, communication technologies and robotics (BMFIT, 2010).

Werner Nachtigall divides the tasks of a biomimetics researcher into three interlinked and chronologically ordered sub-processes:

- **Recognizing** Researching, describing and evaluating the biological basis
- **Abstracting** Abstracting the results of the research, deriving general principles
- **Implementing** these results at a technical level – comparing principles, developing concepts and approaches

Therefore, potential fields of work include research; analysis using high-resolution 3D microscopes as well as electron and atomic force microscopes or CT scanners; computer-aided modelling, simulation and optimization; and carrying out feasibility studies using rapid prototyping.

Technical biology

Technical biology brings together elements of the three main areas: biology, chemistry and process technology. As a sub-division of bio-technology, technical biology looks at how technology can use biological systems or parts of them in order to generate products or convert materials. Biological systems used include bacteria, yeasts, fungi, algae, etc. (microbial biotechnology); plant-based, animal-based and human-based cell cultures (cell culture technology); and isolated or manufactured peptides and proteins. The process includes processing and applying these, e.g. in enzyme technology, bio-catalysis and biosensors). This area is characterized by its high applicability and high level of interdisciplinarity. When it comes to research, technical biology deals in particular with questions related to industrial biotechnology and enzyme technology - e.g. with microbial manufacturing processes or screening / use of enzymes which may be of use to industry.

The description provided above makes it clear that technical biology is a new, interesting and worthwhile option for graduates of the new study program BIE. "Biologists often lack technical knowledge – and this is where biomimetics experts can make an important contribution. They are familiar with both the world of technology and the world of biology. Technical biology represents inverted biomimetics." (Gebeshuber, expert panel for developing study program BIE, 2016).

Product development and construction

Product development and construction aims to develop new products or to improve existing products in order to achieve growth in existing markets (Springer Gabler Verlag, 2016). Biomimetics can contribute to creating genuine innovations in a new or existing market or to improve and expand the product range.

Tasks include those in the

- *planning phase* (developing specification sheets, searching for potential bionic solutions, feasibility studies, rapid prototyping)
- Construction phase (technology research, searching for the "best solution", morphological box, computer-supported topology optimization using finite element programs, generic algorithms, etc.)
- Draft phase (taking into account bionic structures and laws)
- Development phase (taking into consideration the manufacturability)

This is also connected to the communication and collaboration with the interfaces to R&D, technical development and construction as well as transition to production.

Industry and product design

Industry and product design refers to all efforts aimed at making industrial products not only technically viable but also aesthetically pleasing. (Springer Gabler Verlag, 2016).

Nature is a highly efficient, effective and sustainable designer - it wastes nothing and is in a permanent process of self-optimization. The result is perfectly adapted designs with a high level of functionality. Industry and product design aims to learn from nature and apply this knowledge to the challenges of today. This involves first and foremost computer-based activities such as 3D design, functional optimization using finite elements, as well as implementing this knowledge using rapid prototyping.

Production technology

Production technology refers to transforming scientific knowledge into procedures and processes which are understood by humans (from a technological perspective) and at the same time can be integrated into production systems which are financially viable (Springer Gabler Verlag, 2016). Here, process refers to the totality of individual steps within a system. This means processes are used to transport, transform and store materials, energy and information. A production process is a technologically, temporally and locally defined efficient

Collaboration between production factors in order to produce a certain quantity of goods of a certain quality (Springer Gabler Verlag, 2016).

Biomimetics experts can take on many tasks within this context, for example by re-designing these processes when system components and systems themselves change as a result of biomimetics. Furthermore, conventional processes can be made more efficient using optimization programs and more autonomous and intelligent through self-learning properties. The huge volume of data generated by Industry 4.0 and through the Internet of Things can be managed using generic algorithms in order to extract relevant data.

Activities in this area include independent solving of optimization tasks, managing large volumes of data (big data) and developing customer-specific optimization algorithms (generic algorithms, artificial intelligence). This requires systemic thinking as well as skills in the fields of mathematics, informatics and object-oriented programming.

Consulting, business consulting

Consulting refers to the process of analyzing and solving business-related problems in cooperation between external, independent persons or consulting agencies and companies in need of support. (Springer

Gabler Verlag, 2016). Business consulting is a sub-discipline of consulting focusing on services specifically aimed at companies. Although company consulting still makes up the lion's share of consulting services in the business setting, there are an increasing number of other organizations which are also beginning to use consulting services.

As already mentioned, biomimetics requires interdisciplinary expert knowledge. Furthermore, biomimetics is seen in many cases as a sustainable driver of innovation. Therefore, it seems logical that bionics experts can make important contributions in particular in (strategic) consulting for companies, e.g. product management, R&D management and innovation management.

Job prospects

On the website www.studycheck.de there is the following information about job prospects for graduates of bionics: "After graduating you will have outstanding job prospects. Many international companies are looking for bionics specialists. Bionics experts work on new materials or come up with innovative technical solutions in the R&D departments of international companies. Many of these companies can be found in the aerospace industry, vehicle manufacturing, material sciences or bio-medicine."

"After completing a PhD and gathering work experience in this field you can go on to lead your own research group within a company. At a later stage of your career it is also possible to switch to a management role in a company. Those wishing to work in management are advised to complete additional courses on business studies. Many companies will pay for such courses for their employees after a few years in the company. In a university context you can work in research and teaching as an assistant and later as a professor..."

Today there are only few companies and universities which expressly advertise for the position of a "bionics expert". However, the same goes for physicists and nanotechnology experts. Like physicists, bionics experts should also be able to apply their broad knowledge and skills as well as their "way of thinking" (for physicists first and foremost their analytical skills) in order to work their way into in other niche areas of the job market. Large companies may not yet have their own "bionics department", but it makes sense to have 1 or 2 bionics experts in a R&D department with 100 or more researchers. They bring new expertise, a new way of thinking and additional innovative energy to the department and the company in general. Due to its specialized nature, a study program focusing on biomimetics has different requirements from a more general study program with a larger number of students. However, graduates in this field will find an increasing level of demand for their skill-set in the coming years.

In an interview Prof. Emeritus Werner Nachtigall points out that during the years when he taught biomimetics in Saarbrücken there was at that time no clear demand for "bionics experts" (2016). He adds, however, that this was a long time ago. Prof. A. Kesel, Director of Studies for Biomimetics (Hochschule Bremen, Bachelor, Master), speaks of not only a very strong demand but also good job perspectives for graduates of biomimetics (Nachtigall, 2016). Biomimetics experts are generalists and therefore match the much-quoted profile of the "interdisciplinary scientist and engineer" demanded by so many employers.

1.2 Qualification goals / learning outcomes

Graduates of the new international Master in Bio-Inspired Engineering have a broad, interdisciplinary skill-set in the field of technology and natural sciences. This prepares them well for working in many different areas, as described above. These include research and development, technology and product development, construction and design, process and product optimization, founding a company and business consulting.

Below is a summary of the skills and competences which graduates of the Master in Bio-Inspired Engineering acquire over the course of the four semesters.

They know the most important historical steps in the development of biomimetics, from early approaches via the current state of the art to the most important fields of research today. They understand the ecological dimension of biomimetics and are able to critically analyze the sustainability of a bio-inspired product and its manufacturing process. Over the course of the four semesters they learn the most important basics in each of the ten sub-sections of biomimetics, including the history of the discipline. There is a separate module for each sub-section. The repetition of key approaches in several modules ("Biology for Engineers", Technical Principles for Biomimetics, "Biomimetics" and Biomimetics Lab) teach students to approach different sub-sections of biomimetics in the same way. This enables them to develop the necessary understanding of the underlying biological principles, the technical and natural sciences principles and processes, and the application of the biomimetic abstraction process.

The study program teaches students fundamental knowledge of the following areas: Biology: Graduates know the fundamentals required for biomimetics in the areas of botany and zoology, molecular biology and neurobiology, human physiology, microbiology and synthetic biology, theoretical biology and evolutionary biology, self-assembly and molecular machines, ecology and sustainability, biological systems and organization forms. Graduates know and understand the fundamental terms, concepts, principles and processes required for biomimetics and are able to correctly explain these in their own words.

Technology/natural sciences: Graduates know the fundamentals of applied solid-state physics, micro and nano technology, mechanics and fluidics, mechatronics and robotics, photonics, biotechnology and biochemistry, mathematical biology, applied computer sciences as well as cybernetics and systems engineering. Here too, graduates know and understand the fundamental terms, concepts, principles and processes required for biomimetics, and are able to correctly explain these in their own words. The symbiosis of these two perspectives (biology and technology/natural sciences) creates a shared language which builds a bridge between the world of biology and the world of technology – graduates are able to speak this language.

Building on these two overarching fields, students learn about biomimetics in a systematic way. By repeating and practicing the biomimetic abstraction process in all modules using concrete examples, graduates can consolidate their knowledge of this core process. Therefore they are able to apply this process to new problems and tasks.

Thanks to the broad range of skills that students of biomimetics develop, graduates have the ability to familiarize themselves quickly with different sub-disciplines of biomimetics. Furthermore, in the laboratory exercises they have learned about the main methods to efficiently and effectively deal with scientific questions according to the technological state of the art. They know the most important analytical processes, are able to create 2D and 3D models using CAD programs (SolidWorks), to optimize these models using a finite element program (Ansys), and using digital manufacturing systems (Fablab) develop and test prototypes. Furthermore, they are able to create their own small-scale bio-inspired optimization programs using Python.

Over the course of the four semesters the graduates also learn about the innovation process – from the initial idea to the feasibility study and the manufacturing process; they know the main manufacturing processes for existing biomimetic products as well as the strengths, weaknesses and sustainability of these processes.

Last but not least, graduates address a specific aspect of biomimetics in their Master thesis and through this thesis also develop important knowledge about the basics of scientific working and academic writing.

2 ADMISSION CRITERIA

The Master in Bio-Inspired Engineering is an executive study program. As well as the academic requirements set out below, applicants must have at least 3 years of professional experience at the start of the program.

The general admission criteria are set out in the current version of the **University of Applied Sciences Studies Act (FHStG), § 4 and § 9**. This states that the educational requirement for admission to a University of Applied Sciences Master study program shall be a completed subject-relevant University of Applied Sciences Bachelor study program or the completion of an equivalent study program at a recognized domestic or foreign post-secondary educational institution.

1) For this study program, "subject-relevant" refers to Bachelor study programs which focus mainly on the fields of natural sciences and/or engineering. These fields (natural sciences and/or engineering) must make up at least 75% of the study program completed by the applicant (e.g. 135 ECTS in a Bachelor with a total of 180 ECTS or 90 in a Master with 120 ECTS). The Director of Studies is entitled to grant exceptions in individual cases (e.g. if the applicant has completed a Bachelor with less than 75% focus on natural sciences and engineering but attended a technical secondary school such as a "Höhere Technische Lehranstalt").

2) All courses and examinations for this study program are in English. Applicants must provide proof of English skills at least at level C1 according to the Common European Framework (CEF). This proof can be provided in the form of a TOEFL IBT (at least 95) or TOEFL ITP (at least 627). This proof of English language skills must be no older than 10 years at the start of the study program. This requirement does not apply to applicants who either speak English as their first language or have spent at least 2 semesters studying in an English-speaking country. In exceptional situations the Director of Studies is entitled to grant exceptions to this requirement (e.g. the applicant has released publications in English and has provided proof of language skills in an intensive one-on-one conversation setting).

3) The Director of Studies for the Master study program Bio-Inspired Engineering is responsible for checking that each applicant meets the necessary admission criteria.

4) Certificate students must meet the same admission criteria.

3 CURRICULUM

3.1 Curriculum details

Curriculum Details
(Columns "FT" or "PT" or "FT"+"PT" to be filled in depending on how study program is organised)

	FT	PT	Comments
First academic year (YYYY/YY+1)		2017/2018	
Normal duration of studies (number of semesters)		4	
Total course hours (mandatory) (total of all semesters)		60	
Teaching weeks per semester		10 22	Weeks with courses Possible course weeks per se-
Total courses (mandatory) (total of all semesters)		900	
Total ECTS (mandatory) (total of all semesters)		120	
Start of winter semester (Date or calendar week)		Start of September	Correlates with start of semester at MIT
End of winter semester (Date or calendar week)		End of January	
Start of summer semester (Date or calendar week)		Start of February	Correlates with start of semester at MIT
End of summer semester (Date or calendar week)		End of July	
Weeks in winter semester		22	
Weeks in summer semester		22	
Mandatory semester abroad (semester)		No	There is no mandatory semester abroad. A period of time studying abroad is possible in the 4th semester as part of the Biomemetics Lab IV.
Teaching language (to be indicated)		English	
Internship (Semester, duration in weeks per semester)		No	

Resulting from combination of study programs or separation from study program (study program code; only required in case of combination or separation)	No

3.2 Semester-by-semester model of the curriculum

Term 1			
Moduls		**LV**	**ECTS**
Introduction to Bimimetics // Einführung in die Biomimetik	**ITB**		**4**
	ITB1	Biomimetrics: History and Basics in Biomimetics	2
	ITB2	Ecology and Sustainability	2
Materials and Structures // Materialien und Strukturen	**MAS**		**9**
	MAS1	Biology for Engineers: Botany, Zoology	3
	MAS2	Engineering Principles for Biomimetics: Solid State Physics, Nanotechnology	3
	MAS3	Biomimetics: Materials and Structures	3
Design, Construction & Building // Design, Konstruktion & Bau	**DCB**		**9**
	DCB1	Biology for Engineers: Botany, Zoology	3
	DCB2	Engineering Principles for Biomimetics: Mechanics and Mobility, Fluid Dynamics and Nanotechnology	3
	DCB3	Biomimetic: Styling & Design, Constuctions & Equipment	3
Biomimetic-Lab 1 // Biomimetik-Lab 1	**BL1**		**8**
	BL1_1	Imaging Lab 1	2
	BL1_2	Computer Aided Design	2
	BL1_3	Simulation and Optimisation 1	2
	BL1_4	Rapid Prototyping & Manufacturing 1	2
			30

Term 2

Moduls		LV	ECTS
Bimimetics as a Science // Biomimetik als angewandte Wissenschaft	**BSI**		**4**
	BSI1	Best Practice in Scientific Working	2
	BSI2	Biomimetic as a Science	2
Robotic and Locomotion // Robotik und Lokomotion	**RLO**		**7**
	RLO1	Biology for Engineers: Botany, Zoology	2
	RLO2	Engineering Principles for Biomimetics: Mechatronics and Robitic	2
	RLO3	Biomimetics: Locomotion and Robotics	3
Sensors and Neuronal Control // Sensoren und Neuronale Steuerungen	**SNC**		**9**
	SNC1	Biology for Engineers: Molecular- and Neuro-Biology	3
	SNC2	Engineering Principles for Biomimetics: Mechatronics and Photonics	3
	SNC3	Biomimetic: Sensor and Neuronal Control	3
Anthropo - and Biomedical Technology // Anthropo- und biomedizinische Technik	**ABT**		**6**
	ABT1	Biology for Engineers: Human Physiology	2
	ABT2	Engineering Principles for Biomimetics: Biomedical Engineering	2
	ABT3	Biomimetics: Anthropo – and Biomedical Technology	2
Biomimetic-Lab 2 // Biomimetik-Lab 2	**BL2**		**4**
	BL2_1	Simulation and Optimisation 2	1
	BL2_2	Imaging Lab 2	1
	BL2_3	Rapid Prototyping & Manufacturing 2	2
			30

Term 3

Moduls		LV	ECTS
Nature-inspired Innovation // Natur-Inspirierte Innovation	**BIN**		**8**
	BIN1	Technologie and Innovation Management	2
	BIN2	Product Development & Business Plan	3
	BIN3	Sustainable Production of biomemetic products	3
Methods, Processes and Structures // Verfahren und Abläufe	**PAP**		**8**
	PAP1	Biology for Engineers: Mico-Biology and Chemistry for Engineers	3
	PAP2	Engineering Principles for Biomimetics: Applied Micro- and Nanotechnology, Bio-Technology and Chemistry	3
	PAP3	Biomimetics: Procdured and Processes in Nature	2
Evolution and Optimisation // Evolution und Optimierung	**EAO**		**6**
	EAO1	Biology for Engineers: Theoretical & Evolutionary Biology, Self-Assembly & Molecular Machines	2
	EAO2	Engineering Principles for Biomimetics: Mathematical Biology & Applied Compute Science	2
	EAO3	Biomimetic: Evolution and Optimisation	2
Biomimetic-Lab 3 // Biomimetik-Lab 3	**BL3**		**8**
	BL3_1	Imaging Lab 3	2
	BL3_2	Programming	2
	BL3_3	Simulation and Optimisation 3	2
	BL3_4	Rapid Prototyping & Manufacturing 3	2
	BL3_5	Field Trips	
			30

Term 4

Moduls		LV	ECTS
Systemik and Organisation // Systemik und Organisation	**SAO**		**6**
	SAO1	Biology for Engineers: Systemics and Organisation	2
	SAO2	Engineering Principles for Biomimetics: System Engineering and Cybernetics	2
	SAO3	Biomimetics: Systemics and Organisation	2
Biomimetic-Lab 4// Biomimetik-Lab 4	**BL4**		**6**
	BL4_a	Option 1: How to make (almost) anything	
	BL4_b	Option 1: How to grow (almost) anything	6
	BL4_c	Option 3: Field Trip "The rainforest of the Austrians" (Costa Rica)	
Master Thesis	**MAT**		**18**

3.3 Matrix ECTS / distribution of teaching hours

1. Semester

LV-Nr	LV-Bezeichnung	LV-Typ	SWS	Anz.Grpe	ASWS	ALVS	Modul	ECTS
ITB1	Biomimetics: History & Basics in Biomimetics	VL	1,5	1	1,5	22,5	ITB	2
ITB2	Ecology and Sustainability	VL	1,5	1	1,5	22,5	ITB	2
MAS1	Biology for Engineers: Botany, Zoology	VL	2	1	2	30	MAS	3
MAS2	Engineering Principles for Biomimetics: Solid State Physics, Nanotechnology	VL	2	1	2	30	MAS	3
MAS3	Biomimetics: Materials and Structures	VL	2	1	2	30	MAS	3
DCB1	Biology for Engineers: Botany, Zoology	VL	2	1	2	30	DCB	3
DCB2	Engineering Principles for Biomimetics: Mechanics and Mobility, Fluid Dynamics and Nanotechnology	VL	1,6	1	1,6	24	DCB	3
DCB3	Biomimetic: Styling & Design, Constuctions & Equipment	VL	2	1	2	30	DCB	3
BL1_1	Imaging Lab 1	UE	1,2	1	1,2	18	BL_1	2
BL1_2	Computer Aided Design	UE	1	1	1	15	BL_1	2
BL1_3	Simulation and Optimisation 1	UE	1	1	1	15	BL_1	2
BL1_4	Rapid Prototyping & Manufacturing 1	UE	1,2	1	1,2	18	BL_1	2
SUM			**19**	**12**	**19**	**285**		**30**

2. Semester

LV-Nr	LV-Bezeichnung	LV-Typ	SWS	Anz.Grpe	ASWS	ALVS	Modul	ECTS
BSI1	Best Practice in Scientific Working	VL	1	1	1	15	BSI	2
BSI2	Biomimetic as a Science	VL	1	1	1	15	BSI	2
RLO1	Biology for Engineers: Botany, Zoology	VL	1,5	1	1,5	22,5	RLO	2
RLO2	Engineering Principles for Biomimetics: Mechatronics and Robotic	VL	1,2	1	1,2	18	RLO	2
RLO3	Biomimetics: Locomotion and Robotics	VL	2	1	2	30	RLO	3
SNC1	Biology for Engineers: Molecular- and Neuro-Biology	VL	1,5	1	1,5	22,5	SNC	3
SNC2	Engineering Principles for Biomimetics: Mechatronics and Photonics	VL	2	1	2	30	SNC	3
SNC3	Biomimetic: Sensor and Neuronal Control	VL	2	1	2	30	SNC	3
ABT1	Biology for Engineers: Human Physiology	VL	1,2	1	1,2	18	ABT	2
ABT2	Engineering Principles for Biomimetics: Biomedical Engineering	VL	1,2	1	1,2	18	ABT	2
ABT3	Biomimetics: Anthropo – and Biomedical Technology	VL	1,2	1	1,2	18	ABT	2
BL2_1	Simulation and Optimisation 2	UE	0,75	1	0,75	11,25	BL_2	1
BL2_2	Imaging Lab 2	UE	0,75	1	0,75	11,25	BL_2	1
BL2_3	Rapid Prototyping & Manufacturing 2	UE	1,2	1	1,2	18	BL_2	2
SUM			**18,5**	**14**	**18,5**	**277,5**		**30**

3. Semester

LV-Nr	LV-Bezeichnung	LV-Typ	SWS	Anz.Grpe	ASWS	ALVS	Modul	ECTS
BIN1	Technology and Innovation Management	VL	1	1	1	15	BIN	2
BIN2	Product Development & Businessplan	VL	1	1	1	15	BIN	3
BIN3	Sustainable Fabrication of Biomemetic Products	VL	1,5	1	1,5	22,5	BIN	3
PAP1	Biology for Engineers: Mico-Biology and Chemistry for Engineers	VL	2	1	2	30	PAP	3
PAP2	Engineering Principles for Biomimetics: Applied Micro- and Nanotechnology, Bio-Technology and Chemistry	VL	2	1	2	30	PAP	3
PAP3	Biomimetics: Procedures and Processes in Nature	VL	1,5	1	1,5	22,5	PAP	2
EAO1	Biology for Engineers: Theoretical & Evolutionary Biology, Self-Assembly & Molecular Machines	VL	1,2	1	1,2	18	EAO	2
EAO2	Engineering Principles for Biomimetics: Mathematical Biology & Applied Computer Science	VL	1,5	1	1,5	22,5	EAO	2
EAO3	Biomimetic: Evolution and Optimisation	VL	1	1	1	15	EAO	2
BL3_1	Imaging Lab 3	UE	1	1	1	15	BL_3	2
BL3_2	Programming	UE	1	1	1	15	BL_3	2
BL3_3	Simulation and Optimisation 3	UE	1	1	1	15	BL_3	2
BL3_4	Rapid Prototyping & Manufacturing 3	UE	1,2	1	1,2	18	BL_3	2
SUM			**16,9**	**13**	**16,9**	**253,5**		**30**

4. Semester

LV-Nr	LV-Bezeichnung	LV-Typ	SWS	Anz.Grpe	ASWS	ALVS	Modul	ECTS
SAO1	Biology for Engineers: Systemics and Organisation	VL	1	1	1	15	SAO	2
SAO2	Engineering Principles for Biomimetics: System Engineering and Cybernetics	VL	1	1	1	15	SAO	2
SAO3	Biomimetics: Systemics and Organisation	VL	1	1	1	15	SAO	2
BL4_a	Option 1: How to make (almost) anything	UE			0		BL_4	
BL4_b	Option 2: How to grow (almost) anything	UE			0			
BL4_c	Option 3: Field Trip "The rainforest of the Austrians" (Costa Rica)	Excursion			0			6
BL4_d	Option 4: Inclusive Case Study	ILV	2	1	2	30		
MAT	Master Thesis		0,6	15	9	9	MAT	18
SUM			**5,6**	**19**	**14**	**84**		**30**

3.4 Module descriptions

Semester 1 (30 ECTS) - Goals: Introduction to biomimetics, developing common language, teaching basics of biomimetics (focus on biology, physics)			
Module **ITB (4 ECTS)** Introduction to Biomimetics ITB1 Biomimetics: History and Basics (VL/3) ITB3 Ecology & Sustainability (VL/2)			
	Module **MAS (9 ECTS)** Materials & Structures MAS1 Biology for Engineers: Botany, Zoology (VL/3) MAS2 Engineering Principles for Biomimetics: Solid State Physics, Nanotechnology (VL/3) MAS3 Biomimetics: Materials and Structures (VL/3)	*Module* **DCB (9 ECTS)** Design, Constructions & Building DCB1 Biology for Engineers: Botany, Zoology for Engineers (VL/3) DCB2 Engineering Principles for Biomimetics: Mechanics & Mobility, Fluid dynamics & Nanotech. (VL/3) DCB3 Biomimetics: Styling & Design, Constructions & Equipment (VL/3)	
			Module **BL1 (8 ECTS)** Biomimetics Lab 1 BL11 Imaging Lab 1 (UE/2) BL!2 Computer Aided Design (UE/2) BL!3 Simulation & Optimization 1 (UE/2) BL14 Rapid Prototyping & Manufacturing 1 (UE/2)
Semester 2 (30 ECTS) - Goals: Developing an understanding of bionics as a science, teaching further basics of biomimetics (focus biology, electronics, IT), developing skills for scientific analysis, simulation, transformation, protoyping, measurement & testing.			
Module **BSI (4 ECTS)** Biomimetics as a Science BSI1 Best Practice in Scientific Working (VL/2) BSI2 Biomimetics as a Science (VL/2)			
	Module **RLO (7 ECTS)** Robotic and Locomotion RLO1 Biology for Engineers: Botany, Zoology (VL/2) RLO2 Engineering Principles for Biomimetics: Mechatronics and Robotics (VL/2) RLO3 Biomimetics: Locomotion and Robotics (VL/3)	*Module* **SNC (9 ECTS)** Sensors & Neuronal Control SNC1 Biology for Engineers: Molecular- and Neuro-Biology (VL/3) SNC2 Engineering Principles for Biomimetics: Mechatronics and Photonics (VL/3) SNC3 Biomimetics: Sensor and Neuronal Control (VL/3)	
		Module **ABT (6 ECTS)** Anthropo & Biomedical Technology ABT1 Biology for Engineers: Human Physiology (VL/2) ABT2 Engineering Principles for Biomimetics: Biomedical Eng. (VL/2) ABT3 Biomimetics: (VL/2)	*Module* **BL2 (4 ECTS)** Biomimetics Lab 2 BL21 Simulation and Optimization 2 (using Finite Elements) (UE/1) BL22 Imaging Lab 2 (UE/1) BL23 Rapid Prototyping and Manufacturing (UE/2)
Semester 3 (30 ECTS) - Goals: Developing processes for sustainable production of biomimetic products; understanding the innovation process and the challenges of product development; teaching further basics of biomimetics			
Module **BIN (8 ECTS)** Bio-Inspired Innovation BIN1 Technology- und Innovation-Management (VL/2) BIN2 Product Development & Business-Plan (VL/3) BIN3 Sustainable Fabrication of bio-inspired Products (VL/3)	*Module* **PAP (8 ECTS)** Procedures and Processes PAP1 Biology for Engineers: Micro-, Molecular & Synthetic Biology (VL/3) PAP2 Engineering Principles for Biomimetics: Applied Micro- & Nano-technology; Bio-Technology & Chemistry (VL/3) PAP3 Biomimetics: Procedures and Processes in Nature (VL/2)	*Module* **EAO (6 ECTS)** Evolution & Optimization EAO1 Biology for Engineers: Theoretical & Evolutionary Biology, Self-Assembly, & Molecular Machines (VL/2) EAO2 Engineering Principles for Biomimetics: Mathematical Biology & Applied Computer Sciences (VL/2) EAO3 Biomimetics: Evolution and	*Module* **BL3 (8 ECTS)** Biomimetics Lab 3 BL31 Imaging Lab 3 (UE/2) BL32 Programming-Lab (UE/2) BL33 Simulation and Optimization 3 (using finite elements) (UE/2) BL34 Rapid Prototyping & Manufacturing 3 (UE/2)
Semester 4 (30 ECTS) - Goals: Further knowledge of manufacturing processes, teaching further basics of biomimetics, Master thesis			
Module **MAT (18 ECTS)** Master Theses		*Module* **SAO (6 ECTS)** Systemics and Organization SAO1 Biology for Engineers: Systemics and Organization (VL/2) SAO2 Engineering Principles for Biomimetics: Systems engineering and Cybernetics (VL/2) SAO3 Biomimetics: Systemics und Organization (VL/2)	*Module* **BL4 (6 ECTS)** Biomimetics Lab 4 UE Option 1: How to make (almost) anything UE Option 2: How to grow (almost) anything UE Option 3: Field Trip "The Rainforest of the Austrians" (Costa Rica) UE Option 4: Inclusive Case Study

The table above provides an overview of the 4th semester and the 16 modules of the Master study program Bio-Inspired Engineering. The vertical axis is the time axis, showing how the modules are connected from a time perspective. On the right-hand side is the respective lab module; in the middle is the respective core module. For details on the abbreviations ("module number"), please refer to the modules and submodules described below.

3.4.1 Semester 1

Module number: **ITB**	Module title: **Introduction to Biomimetics** (4 ECTS / English)
Study program	**Bio-Inspired Engineering**
Position in curriculum	1st semester
Categorization	Biomimetics
Level	Introduction
Previous knowledge	-
Block course	Yes
Participating students	Study program and certificate students
Contributes to following modules	**MAS, SDCE** and all modules of semesters 2, 3 and 4
Recommended reading	Biomimetics History and Basics • Bar-Cohen, Yoseph. *Biomimetics: Nature-based innovation*. CRC press, 2011. • Lorenz, Konrad, and Marjorie Kerr Wilson. *King Solomon's ring: new light on animal ways*. Psychology Press, 2002. • Nachtigall, Werner, and Alfred Wisser. *Bionics by Examples*. Springer, 2015. Ecology and Sustainability • Smith, Thomas M. and Smith, Robert Leo. *Elements of Ecology* (8th Edition), 2012 • Zipf, George Kingsley. *Human behavior and the principle of least effort: An introduction to human ecology*. Ravenio Books, 2016.
MOOCs	Ecology and Sustainability • Introduction to Environmental Science (Dartmouth)

Acquisition of skills	Biomimetics History and Basics The students • Know the "pre-history and early history" as well as the "classic period" and the "modern period" of biomimetics. • Are able to understand and explain historical examples (cases) of the biomimetic process. • Know the most important terms of biomimetics. • Understand the main concepts and principles of biomimet-ics. • Know the fundamentals of the theory of evolution and genetics. • Understand the difference between biomimetics and the neighboring disciplines of technical biology and biotechnol-ogy. • Understand the meaning of functional analogy. • Have an overview of programming languages. Ecology and Sustainability The students • Know the fundamentals of ecology • Understand the most important ideas and concepts in ecology • Know the fundamentals of sustainability • Understand the challenging of sustainable product develop-ment and industrial manufacturing of biomimetic products • Are able to critically analyze the sustainability of biomimetic products

Course title	Biomimetics: History and Basics
Number of ECTS	2 ECTS
Position in curriculum	1st semester/module ITB
Teaching & learning methods	Lecture
Examination methods	Examination module ITB
Course content	Critical analysis of historical examples (cases) from the • Pre-history, • Early history • Classic period and • Modern period of biomimetics Introduction to biomimetics • Fundamental terms from biomimetics • Bionic processes: Concepts & principles of biomimetics • Functional analogies • Fundamentals of the theory of evolution and genetics. • Position of biomimetics in the scientific landscape and differ-entiation between biomimetics and other disciplines such as biology and biotechnology • Overview of biomimetics
Course title	Ecology and Sustainability
Number of ECTS	2 ECTS
Position in curriculum	1st semester/module ITB
Teaching & learning methods	Lecture
Examination methods	Examination module ITB

Course content	• Fundamentals of ecology • Ecological systems, processes and connections • Fundamentals of sustainability • Challenges of sustainable product development and industrial manufacturing of biomimetic products Case Studies: Sustainability of biomimetic products MOOCs: MOOC reflection: Introduction to Environmental Science (Dartmouth)

Module number: **MAS**	Module title: **Materials and Structures** (9 ECTS / English)
Study program	**Bio-Inspired Engineering**
Position in curriculum	1st semester
Categorization	First sub-section of biomimetics (biological, technical, biomimetic and practical basics)
Level	Introduction
Previous knowledge	-
Block course	Yes
Participating students	Study program and certificate students
Contributes to following modules	**BL1**
Recommended reading	Biology for Engineers: Botany, Zoology • Mauseth, James. D. *Botany: An Introduction to Plant Biology*. Jones & Bartlett Learning; 5 edition (September 11, 2012). • Stephen and Harley, John. *Zoology*. McGraw-Hill Education; 9 edition (2012) Engineering Principles for Biomimetics: Solid State Physics, Nanotechnology • Brodie, Ivor, and Julius J. Muray. *The physics of mi- cro/nano-fabrication*. Springer Science & Business Media, 2013. • Kittel, Charles. Introduction to Solid State Physics. Wiley, 8th edition (2004) Biomimetics Materials and Structures • Bar-Cohen, Yoseph. *Biomimetics: Nature-based innovation*. CRC press, 2011. • Nachtigall, Werner, and Alfred Wisser. *Bionics by Examples*. Springer, 2015.

MOOCs	<u>Biology for Engineers: Botany, Zoology</u> • Introduction to Biology - The Secret of Life (MIT) <u>Engineering Principles for Biomimetics: Solid State Physics, Nano-technology</u> • Elements of Structures (MIT) <u>Biomimetics; Materials and Structures</u> • Cellular Solids 1: Structures, Properties and Engineering Applications (MIT)
Acquisition of skills	<u>Biology for Engineers: Botany, Zoology</u> The students • Know and understand the fundamentals of biology required for biomimetics – plant morphology, plant physiology, plant systematics, geological and field botany (relevant for biomimetics)
	• Have a basic understanding and an overview of botanical examples of "bio-inspired materials and structures" • Know the fundamentals and specifics of zoology and systematics/taxonomy required for biomimetics • Have a basic understanding and an overview of zoological examples of "bio-inspired materials and structures" <u>Engineering Principles for Biomimetics: Solid State Physics, Nano-technology</u> The students • Know and understand the fundamentals of applied solids/surfaces/boundary physics required for biomimetics • Know the most important physical properties and understand the mechanisms and processes which can influence them • Know and understand the fundamentals of applied micro-technology and nano-technology required for biomimetics • Know the fundamentals of bio-photonics • Understand the opportunities offered by quantum mechanic phenomena for new material properties • Have a basic understanding of important processes such as self-organization, nano-layers and nano-composites <u>Biomimetics Materials and Structures</u> The students • Know and understand the most important examples of bio-inspired materials and structures • Are able to describe the biomimetic abstraction process using examples • Are able to critically analyze the sustainability of simple biomimetic applications and their production process

Course title	Biology for Engineers: Botany, Zoology
Number of ECTS	3 ECTS
Position in curriculum	1st semester/module MAS
Teaching & learning methods	Lecture, eLearning
Examination methods	Examination module MAS + assignments
Course content	• Fundamentals of botany – plant morphology, plant physiology, plant systematics, geo-botany and field botany (with reference to module MAS) • Biological examples - Working together to create a portfolio of examples from the natural world for the category "materials and structures" • Fundamentals and specifics of zoology and systematics/taxonomy required for biomimetics • Biological examples - Working together to create a portfolio of zoological examples for the category "materials and structures" • Excursion (botanical garden) • Analytics Lab (microscopy)
	• MOOC reflection "Introduction to Biology - The Secret of Life" (MIT)
Course title	Engineering Principles for Biomimetics: Solid State Physics, Nanotechnology
Number of ECTS	3 ECTS
Position in curriculum	1st semester/module MAS
Teaching & learning methods	Lecture, eLearning
Examination methods	Examination module MAS + assignments
Course content	• Fundamentals of applied solids/surfaces/boundary physics • Knowledge of the most important physical properties • Knowledge of the most important mechanisms and processes which influence these physical properties • Fundamentals of applied micro-technology and nano-technology • Fundamentals of bio-photonics • Opportunities offered by quantum mechanic phenomena for new material properties • Basic understanding of important processes such as self-organization, nano-layers, nano-composites, etc.
Course title	Biomimetics: Materials and Structures
Number of ECTS	3 ECTS
Position in curriculum	1st semester/module MAS
Teaching & learning methods	Lecture, eLearning
Examination methods	Examination module MAS + assignments

Course content	• Understanding bio-inspired materials and structures using examples. Examples include biopolymers, monomers, bio-compatible materials, composite materials, self-repairing composites, silk, byssus, bio-based natural fiber composites, bio-based and biodegradable plastics, algae-based and fungus-based materials, biomaterials from waste (e.g. chitin, cellulose, polylactic acid, etc.) • The biomimetic abstraction process and its application • Critical analysis of the sustainability of biomimetic applications and their manufacturing processes • Excursions • Analytics Lab • MOOC reflection: "Cellular Solids 1: Structures, Properties and Engineering Applications" (MIT)

Module number: **DCB**	Module title: **Design, Constructions & Building** (**Styling & Design, Constructions & Equipment, Building & Climatization)** (9 ECTS / English)
Study program	**Bio- Inspired Engineering**
Position in curriculum	1st semester
Categorization	Second, third and fourth sub-section of biomimetics (biological, technical, biomimetic and practical fundamentals)
Level	Introduction
Previous knowledge	
Block course	Yes
Participating students	Study program and certificate students
Contributes to following modules	**BL1**

Recommended reading	Biology for Engineers: Botany, Zoology for Engineers • Mauseth, James. D. *Botany: An Introduction to Plant Biology.* Jones & Bartlett Learning; 5 edition (September 11, 2012). • Miller, Stephen and Harley, John. *Zoology*. McGraw-Hill Education; 9 edition (2012) Engineering Principles for Biomimetics: Mechanics and Mobility, Fluid Dynamics and Nanotechnology • Anderson Jr., John D. *Fundamentals of Aerodynamics*. McGraw-Hill Education; 5th edition (2010). • Munson, Bruce R.; Rothmayer, Alric P., Okiishi, Theodore H.; Huebsch, Wade W. *Fundamentals of Fluid Mechanics.* Wiley; 7 edition (2012). • Rogers, Ben, Adams, Jesse and Pennathur, Sumita. Nano- technology: *Understanding Small Systems* (Mechanical and Aerospace Engineering Series). CRC Press; 3 edition (2014) Biomimetics Styling & Design, Constructions & Equipment • Bar-Cohen, Yoseph. *Biomimetics: Nature-based innovation*. CRC press, 2011. • G. Pohl und W. Nachtigall. Biomimetics for Architecture & Design: Nature – Analogies – Technology. Springer Interna- tional Publishing, Switzerland, 2nd Edition (2015). • Goel, Ashok K., Daniel A. McAdams, and Robert B. Stone. Biologically Inspired Design. Springer, 2015.
MOOCs	Biology for Engineers: Botany, Zoology for Engineers • Introduction to Biology - The Secret of Life (MIT) Engineering Principles for Biomimetics: Mechanics and Mobility, Fluid Dynamics and Nanotechnology • Introduction to Aerodynamics (MIT)
	Biomimetics Styling & Design, Constructions & Equipment • Cellular Solids Part 3: Applications in Nature (MIT)

<table>
<tr><td>Acquisition of skills</td><td><u>Biology for Engineers: Botany, Zoology</u>
The students
Know and understand the fundamentals of biology required for botany – plant morphology, plant physiology, plant systematics (in particular with reference to this module)
Have a basic understanding and an overview of <u>botanical</u> examples of "bio-inspired styling and design" and "bio-inspired constructions and equipment" (e.g. lightweight structures, biological support and shell structures, etc.)
Know and understand the fundamentals of zoology (morphology, anatomy and physiology) required for biomimetics
Have a basic understanding and an overview of <u>zoological</u> examples of "bio-inspired styling
& design" and "bio-inspired constructions & equipment" (e.g. lightweight structures, biological support and shell structures, etc.)
<u>Engineering Principles for Biomimetics: Mechanics and Mobility, Fluid Dynamics and Nanotechnology</u>

The students
Know and understand the fundamentals of applied mechanics and dynamics required for biomimetics
Know and understand the fundamentals of fluid dynamics required for biomimetics
Know and understand the fundamentals of aerodynamics required for biomimetics
Know and understand the fundamentals of nanotechnology required for biomimetics
<u>Biomimetics Styling & Design, Constructions & Equipment</u>

The students
Know and understand the most important examples in the field of
bio-inspired styling and design
Know and understand the most important examples in the field of bio-inspired constructions and equipment
Are able to describe the biomimetic abstraction process using specific examples
Are able to critically analyze the sustainability of simple biomimetic applications and their production process</td></tr>
<tr><td>Course title</td><td>Biology for Engineers: Botany, Zoology</td></tr>
<tr><td>Number of ECTS</td><td>3 ECTS</td></tr>
<tr><td>Position in curriculum</td><td>1st semester/module DCB</td></tr>
<tr><td>Teaching & learning methods</td><td>Lecture, eLearning</td></tr>
<tr><td>Examination methods</td><td>Examination module DCB + assignments</td></tr>
</table>

Course content	• Fundamentals of botany for engineers - plant morphology, plant physiology and plant systematics with focus on the requirements of biomimetics and the module SDCE. • Working together to develop a portfolio of botanical examples in the category "styling and design" using examples (e.g. lightweight structures, biological support and shell structures, etc.) • Working together to develop a portfolio of botanical examples in the category "styling and design" (e.g. lightweight structures, biological support and shell structures, etc.). • Fundamentals of zoology (morphology, anatomy and physiology) • Working together to develop a portfolio of zoological examples in the category "styling and design" (e.g. lightweight structures, biological support and shell structures, etc.). • Working together to develop a portfolio of zoological examples in the category "constructions & equipment" (e.g. lightweight structures, biological support and shell structures, etc.) • Excursion • Analytics Lab (microscopy) • MOOC reflection "Introduction to Biology - The Secret of Life" (MIT)
Course title	Engineering Principles for Biomimetics: Mechanics and Mobility, Fluid Dynamics and Nanotechnology
Number of ECTS	3 ECTS
Position in curriculum	1st semester/module DCB
Teaching & learning methods	Lecture, eLearning
Examination methods	Examination module DCB + assignments
Course content	• Fundamentals of mechanics and dynamics for biomimetics (statics, Newton's laws of motion in 3 dimensions, harmonic oscillator, forced vibration, resonance, etc.) • Fundamentals of fluid dynamics (fluids and fluid mechanics) • Fundamentals of aerodynamics for biomimetics (buoyancy, resistance, angle of attack, stall-effect, etc.) • Fundamentals of nanotechnology for biomimetics (microsystems and nanosystems) • MOOC reflection: - Introduction to Aerodynamics (MIT) - Dynamics (MIT) - Elements of Structures (MIT) - Symmetry, Structure and Tensor Properties of Materials (MIT)
Course title	Biomimetics: Styling & Design, Constructions & Equipment
Number of ECTS	3 ECTS
Position in curriculum	1st semester/module DCB
Teaching & learning methods	Lecture, eLearning
Examination methods	Examination module DCB + assignments

Course content	• Introduction to biological structures (non-functional vs. functional styling, bio/nature-inspired design, etc.) • Case studies "bio-inspired styling and design" • Introduction to "construction and equipment" (construction morphology for lightweight buildings, improved physical properties - e.g. through use of functional technical layers and hierarchical microstructures; how are complex biological systems structured; interaction between construction elements, ideas for connecting, supporting, pumping, turbine and conveyor systems, hydraulics, energy systems, microrobotics, storage principles, etc.) • Introduction to "construction & climate control" (animal constructions, natural construction principles, lightweight constructions, covering and shell constructions, use of surfaces, optimization of surfaces, building bionics. Biomorphic vs. bionic architecture, multifunctionality, diatoms, super-hydrophile, hydrophobe, self-cleaning surfaces, biogenic fibers for textiles, biomimetics for architecture and buildings, natural functions, hierarchical structures, symbiotic building techniques, use of porous materials, phase change materials, innovative floor plans, new ideas for the construction industry when it comes to sustainability, energy technology and consumption of resources, "pneu principle", tensairity principle, self-healing, textiles for insulation, structured paints for optical effects, heat insulation, marking, torsional buckling, etc.) • Case studies "bio-inspired constructions and equipment" • Practicing and independently applying the biomimetic abstraction process using cases • Sustainability of biomimetic applications and their manufacturing processes • Excursion • Analytics Lab (microscopy) • MOOC reflection "Cellular Solids Part 3: Applications in Nature" (MIT)

Module number: **BL1**	Module title: **Biomimetics Lab 1** (8 ECTS / English)
Study program	**Bio- Inspired Engineering**
Position in curriculum	1st semester
Categorization	Lab and Practical Application for the modules **MAS** and **SDCE**
Level	Introduction
Previous knowledge	**MAS, SDCE**
Block course	Yes
Participating students	Study program and certificate students
Contributes to following modules	
Recommended reading	Imaging Lab 1 • Robinson, David G., et al. Methods of preparation for electron microscopy: an introduction for the biomedical sciences. Springer Science & Business Media, 2012. • Nachtigall, Werner. Exploring with the Microscope (A Book of Discovery & Learning). Sterling (1997) Computer Aided Design • Schilling, Paul, and Randy Shih. Parametric Modeling with SOLIDWORKS 2015. SDC Publications, 2015. • Shih, Randy. Learning SolidWorks 2015. Sdc Publications, 2015. Simulation and Optimization 1 • Bendsoe, Martin Philip, and Ole Sigmund. Topology optimi- za- tion: theory, methods, and applications. Springer Science & Business Media, 2013. • Haupt, Randy L., and Sue Ellen Haupt. Practical genetic al- gorithms. John Wiley & Sons, 2004. • Madenci, Erdogan, and Ibrahim Guven. The finite element method and applications in engineering using ANSYS®. Springer, 2015. • Mitchell, Melanie. An introduction to genetic algorithms. MIT press, 1998. Rapid Prototyping & Manufacturing 1 • Gershenfeld, Neil. *Fab: the coming revolution on your desk- top--from personal computers to personal fabrication*. Basic Books, 2008. • Pham, Duc, and Stefan S. Dimov. Rapid manufacturing: the technologies and applications of rapid prototyping and rapid tooling. Springer Science & Business Media, 2012. • Venuvinod, Patri K., and Weiyin Ma. Rapid prototyping: la- ser- based and other technologies. Springer Science & Busi- ness Media, 2013.
MOOCs recommendations	Simulation and Optimization 1 • Introduction to Computer Science (Harvard) • Hands-on Introduction to Engineering Simulations (Cornell)
Acquisition of skills	Imaging Lab 1

	The students • Know the functioning, areas of application, opportunities, limitations and preparation techniques for the main analytical imaging techniques for biomimetics (light microscope, 3D microscope, REM, Micro CT, OCT, MRI, ultrasound) • Are able to work independently using the abovementioned techniques (e.g. 3D light microscope, REM, Micro CT) • Are able to generate and analyze geometrics using these techniques <u>Computer Aided Design</u> The students • Know the opportunities offered by modern CAD programs • Are able to transform complex sketches from the field of biomimetics into 3D designs (functional and parameterized) using a CAD program <u>Simulation and Optimization 1</u> The students • Know and understand the opportunities of modern simulation and optimization programs • Know and understand the fundamentals, opportunities and limitation of simulation and optimization using finite elements • Are able to simulate and optimize simple simulation and optimization tasks (e.g. topology optimization) from the field of biomimetics using a finite elements program (Ansys) with focus on computer-aided optimization, soft kill option) <u>Rapid Prototyping & Manufacturing 1</u> The students • Know and understand the fundamentals, opportunities and limitation of additive manufacturing • Know and understand the fundamentals, opportunities and limitation of prototype manufacturing in Fablab (e.g. 3D printing, 3D scan, laser cutting, CNC manufacturing, robotic assisted design, stereo lithography, etc.) • Are able to independently produce and test biomimetic prototypes in Fablab
Course title	Imaging Lab 1
Number of ECTS	2 ECTS
Position in curriculum	1st semester module/BL1
Teaching & learning methods	Practical exercise, eLearning
Examination methods	Project BL1 + assignments
Course content	• Functioning, areas of application, opportunities, limitations and preparation techniques for the main analytical imaging techniques for biomimetics (light microscope, 3D microscope, REM, Micro CT, OCT, MRI, ultrasound) • Introduction to how to safely use the abovementioned systems (e.g. 3D light microscope, REM, Micro CT)

	• Exercises using the abovementioned systems (e.g. 3D light microscope, REM, Micro CT) • Digital generation and analysis of geometrics using the abovementioned systems • Exercises/project
Course title	Computer Aided Design
Number of ECTS	2 ECTS
Position in curriculum	1st semester module/BL1
Teaching & learning methods	Practical exercise, eLearning
Examination methods	Project + assignments
Course content	• State of the art, opportunities and limitations of modern CAD programs • Sketching biometric structures and functions • 2D/3D and 4D design of biometric structures and functions using SolidWorks (functional & parameterized)
Course title	Simulation and Optimization 1
Number of ECTS	2 ECTS
Position in curriculum	1st semester module/BL1
Teaching & learning methods	Practical exercise, eLearning
Examination methods	Project + assignments
Course content	• State of the art and opportunities of modern simulation and optimization programs • Fundamentals, opportunities and limitation of simulation and optimization using finite elements • Simulation and optimization in the field of biomimetics (e.g. topology optimization) using a finite elements program (Ansys) with a focus on computer-aided optimization, soft skill option, etc. • Exercises/project
Course title	Rapid Prototyping & Manufacturing 1
Number of ECTS	2 ECTS
Position in curriculum	1st semester module/BL1
Teaching & learning methods	Practical exercise, eLearning
Examination methods	Project + assignments
Course content	• Fundamentals, state of the art, opportunities and limitations of additive manufacturing • Know and understand the fundamentals, opportunities and limitation of additive manufacturing • Ability to independently use rapid prototyping tools in Fablab (e.g. 3D printing, 3D scan, laser cutting, CNC manufacturing, robotic assisted design, stereo lithography, etc.) • Ability to independently produce and test biomimetic prototypes in Fablab

3.4.2 Semester 2

Module number: **BSI**	Module title: **Biomimetics as a Science** (4 ECTS / English)
Study program	**Bio-Inspired Engineering**
Position in curriculum	2nd semester
Categorization	Introduction to biomimetics
Level	Introduction
Previous knowledge	-
Block course	Yes
Participating students	Study program and certificate students
Contributes to following modules	RLO, SNC, ABT as well as all modules of semesters 3 and 4
Recommended reading	Best Practice in Scientific Working • Gauch, Hugh G., Jr. (2003), Scientific Method in Practice, Cambridge University Press, ISBN 0-521-01708-4 435 pages • James T. McClave and Terry T Sincich. Statistics. Pearson; 12 edition (2012). • Kate L. Turabian. A Manual for Writers of Research Papers, Theses, and Dissertations, Eighth Edition: Chicago Style for Students and. University Of Chicago Press; 8 edition (March 28, 2013) • Max Planck Gesellschaft. Rules of Good Scientific Practice (2009). Biomimetics as a Science • Bar-Cohen, Yoseph. *Biomimetics: Nature-based innovation*. CRC press, 2011. • Von Gleich, Arnim, et al. Potentials and trends in biomimet- ics. Springer Science & Business Media, 2010. • W. Nachtigall. Bionik als Wissenschaft. Springer-Verlag Ber- lin Heidelberg (2010) • Y. Helfmna Cohen, Y. Reich. Biomimetic Design Method for Innovation and Sustainability. Springer Verlag (2016).
MOOCs	Biomimetics as a Science • Statistical Thinking for Data Science and Analytics (Columbia)

Acquisition of skills	Best Practice in Scientific Working The students • Know and understand the most important concepts and ideas of scientific working • Know and understand the best practice of scientific working • Know and understand the most important concepts of statistics and are able to apply these to new examples independently • Are able to carry out comprehensive literary research efficiently, effectively and in a reflected way • Know and understand the fundamentals of technology observation and prognosis • Know and understand the basic ideas and concepts of scientific ethics
	• Know and understand the best practice of "scientific writing" Biomimetics as a Science The students • Main areas of research in the field of biomimetics • Are familiar with and understand the main points expressed by W. Nachtigall in his work "Biomimetik als Wissenschaft" (2010) – this includes knowing and understanding the meaning of abstraction in biomimetics ("using abstracted principles of nature for technology"). Furthermore, they are able to independently apply the "three-step path of biomimetics" using cases 1) Exploring the living world – recognizing relations between structure and function 2) Abstraction of general principles from original biological data 3) Appropriate technical implementation of general principles through to realization.
Course title	Best Practice in Scientific Working
Number of ECTS	2 ECTS
Position in curriculum	2nd semester module/BSI
Teaching & learning methods	Lecture, eLearning
Examination methods	Examination BSI + assignments
Course content	• Concepts and fundamentals of scientific working • "Best practice" of scientific working • Fundamentals of statistics with examples • Literature research (publications, patents) online and in databases • Fundamentals of technology observation and prognosis • Fundamentals of scientific ethics • Best practice in "scientific writing"
Course title	Biomimetics as a Science
Number of ECTS	2 ECTS
Position in curriculum	2nd semester module/BSI
Teaching & learning methods	Lecture, eLearning
Examination methods	Examination BSI + assignments

Course content	• Overview of areas of research in the field of biomimetics • The significance of abstraction in biomimetics • Introduction to the "three-step path of biomimetics" • Exercise: Independent use of abstraction and the three-step path using biomimetic examples • MOOCs reflection: - Statistical Thinking for Data Science and Analytics (Columbia)

Module number: **RLO**	Module title: **Robotics and Locomotion** (8 ECTS / English)
Study program	**Bio-Inspired Engineering**
Position in curriculum	2nd semester
Categorization	Fifth sub-section of biomimetics (biological, technical, biomimetic and practical basics)
Level	Introduction
Previous knowledge	1st semester
Block course	Yes
Participating students	Study program and certificate students
Contributes to following modules	BL2 as well as all modules of the 3rd and 4th semester
Recommended reading	<u>Biology for Engineers: Botany, Zoology</u> • Alexander, R. McNeill. Principles of animal locomotion. Princeton University Press, 2003. • Rosenhahn, Bodo, Reinhard Klette, and Dimitris Metaxas, eds. Human motion: understanding, modelling, capture, and animation. Vol. 36 Springer Science & Business Media, 2007. • Taylor, Graham, Michael S. Triantafyllou, and Cameron Tropea, eds. Animal locomotion. Springer Science & Busi- ness Media, 2010. <u>Engineering Principles for Biomimetics: Mechatronics and Robotics</u> • Anderson Jr., John D. *Fundamentals of Aerodynamics*. McGraw-Hill Education; 5th edition (2010). • Isermann, Rolf. Mechatronic systems: fundamentals. Springer Science & Business Media, 2007. • Munson, Bruce R.; Rothmayer, Alric P., Okiishi, Theodore H.; Huebsch, Wade W. *Fundamentals of Fluid Mechanics.* Wiley; 7 edition (2012). • Siciliano, Bruno, and Oussama Khatib, eds. Springer hand- book of robotics. Springer Science & Business Media, 2008. <u>Biomimetics Locomotion and Robotics</u> • Bekey, George A. Autonomous robots: from biological inspi- ration to implementation and control. MIT press, 2005. • Floreano, Dario, et al., eds. Flying insects and robots. Ber- lin: Springer, 2010. • Siegwart, Roland, Illah Reza Nourbakhsh, and Davide Scaramuzza. Introduction to autonomous mobile robots. MIT press, 2011. • Webb, Barbara, and Thomas Consilvio. Biorobotics. MIT Press, 2001. <u>Bio-Robotic Lab</u> • Villanueva, Alex, et al. "Jellyfish inspired underwater unmanned vehicle." SPIE Smart Structures and Materials+ Nondestructive Evaluation and Health Monitoring. International Society for Optics and Photonics, 2009.
MOOCs	<u>Biology for Engineers: Botany, Zoology</u> • Introduction to Biology - The Secret of Life (MIT)

<table>
<tr><td></td><td><u>Engineering Principles for Biomimetics: Mechatronics and Robotics</u>
Introduction to Aerodynamics (MIT)
Elements of Structures (MIT)
<u>Biomimetics; Locomotion and Robotics</u>
Underactuated Robotics (MIT)
Autonomous Mobile Robots (ETH Zurich)</td></tr>
<tr><td>Acquisition of skills</td><td><u>Biology for Engineers: Botany, Zoology</u>
The students
Know and understand the biological principles of locomotion and movement (walking, running, swimming, flying, crawling, etc.) necessary for biomimetics, from small creatures (micro-organisms, insects) to large creatures (giant manta rays, whales, etc.)
Know and understand the fundamentals of functional morphology
Create an initial portfolio of biological examples in the category movement
<u>Engineering Principles for Biomimetics: Mechatronics and Robotics</u>
The students
Know and understand the fundamentals of mechatronics required for biomimetics (e.g. kinematics, operation & control technology, control engineering, interfaces, actuators, electrostatics, electrokinetics, electrodynamics)
Know and understand the fundamentals of aerodynamics, fluid dynamics, mechanics of fluids required for biomimetics (e.g. boundary layer effects, resistance values, indicated resistance, areas of overpressure/underpressure, buoyancy, flow-stall, pneumatics, Reynolds number, reduced frequency)
Know and understand the state of the art in robotics
<u>Biomimetics Locomotion and Robotics</u>
The students
Know and understand the most important examples in the field of bio-inspired locomotion and robotics (e.g. bio-inspired movements models, autostable running machines, motor and gearing technologies, coordination and controlling, grasping and handling technology, applications for land, water and air transport; applications for unmanned macro and micro vehicles)
Are able to describe the biomimetic abstraction process using examples
Are able to critically analyze the sustainability of biomimetic applications and their manufacturing processes</td></tr>
<tr><td>Course title</td><td>Biology for Engineers: Botany, Zoology</td></tr>
<tr><td>Number of ECTS</td><td>2 ECTS</td></tr>
<tr><td>Position in curriculum</td><td>2nd semester/module RLO</td></tr>
<tr><td>Teaching & learning methods</td><td>Lecture, eLearning</td></tr>
</table>

Examination methods	Examination module RLO + assignments
Course content	• Biological principles of locomotion and movement (walking, running, swimming, flying, crawling, etc.) necessary for biomimetics, from small creatures (micro-organisms, insects) to large creatures (giant manta rays, whales, etc.) • Fundamentals of functional morphology • Have a basic understanding and an overview of biological examples of movement (relevant for biomimetics) • MOOC reflection "Introduction to Biology - The Secret of Life" (MIT)
Course title	Engineering Principles for Biomimetics: Mechatronics and Robotics
Number of ECTS	2 ECTS
Position in curriculum	2nd semester/module RLO
Teaching & learning methods	Lecture, eLearning
Examination methods	Examination module RLO + assignments
Course content	• Aspects of mechatronics relevant for biomimetics (e.g. kinematics, operation & control technology, control engineering, interfaces, actuators, electrostatics, electrokinetics, electrodynamics) • Fundamentals of aerodynamics, fluid dynamics, mechanics of fluids required for biomimetics (e.g. boundary layer effects, resistance values, indicated resistance, areas of overpressure/underpressure, buoyancy, flow-stall, pneumatics, Reynolds number, reduced frequency) • State of the art in robotics • MOOC reflection: - Introduction to Aerodynamics (MIT)
Course title	Biomimetics: Locomotion and Robotics
Number of ECTS	3 ECTS
Position in curriculum	2nd semester/module RLO
Teaching & learning methods	Lecture, eLearning
Examination methods	Examination module RLL + assignments
Course content	• Case studies of bio-inspired locomotion and robotics (e.g. bio-inspired movements models, autostable running machines, motor and gearing technologies, coordination and controlling, grasping and handling technology, applications for land, water and air transport; applications for unmanned macro and micro vehicles) • The biomimetic abstraction process using cases from the field of "locomotion and robotics" • Sustainability of biomimetic applications and their manufacturing processes • MOOC reflection: - Underactuated Robotics (MIT) - Autonomous Mobile Robots (ETH Zurich)

Module number: **SNC**	Module title: **Sensor and Neuronal Control** (8 ECTS / English)
Study program	**Bio-Inspired Engineering**
Position in curriculum	2nd semester
Categorization	Sixth sub-section of biomimetics (biological, technical, biomimetic and practical basics)
Level	Introduction
Previous knowledge	1st semester
Block course	Yes
Participating students	Study program and certificate students
Contributes to following modules	**ABT, BL2**
Recommended reading	<u>Biology for Engineers: Molecular- and Neuro-Biology</u> • Davis, Leonard. Basic methods in molecular biology. Elsevier, 2012. • Siegelbaum, Steven A., and A. J. Hudspeth. Principles of neural science. Eds. Eric R. Kandel, James H. Schwartz, and Thomas M. Jessell. Vol. 4. New York: McGraw-hill, 2000. • Bruce, Vicki, Patrick R. Green, and Mark A. Georgeson. Visual perception: Physiology, psychology, & ecology. Psychology Press, 2003. • Howes, David. Empire of the Senses. Oxford: Berg Publishers, 2005. <u>Engineering Principles for Biomimetics: Mechatronics and Photonics</u> • Isermann, Rolf. Mechatronic systems: fundamentals. Springer Science & Business Media, 2007. • Lillesand, Thomas, Ralph W. Kiefer, and Jonathan Chipman. Remote sensing and image interpretation. John Wiley & Sons, 2014. • Novotny, Lukas, and Bert Hecht. Principles of nano-optics. Cambridge university press, 2012. • Saleh, Bahaa EA, Malvin Carl Teich, and Bahaa E. Saleh. Fundamentals of photonics. Vol. 22. New York: Wiley, 1991. <u>Biomimetics Sensor and Neuronal Control</u> • Ayers, Joseph, Joel L. Davis, and Alan Rudolph. Neurotech- nology for biomimetic robots. MIT press, 2002. • Barth, Friedrich G., Joseph AC Humphrey, and Timothy W. Secomb, eds. Sensors and sensing in biology and engineering. Springer Science & Business Media, 2012. • Prasad, Paras N. Introduction to biophotonics. John Wiley & Sons, 2004.
MOOCs recommendations	<u>Biology for Engineers: Molecular- and Neuro-Biology</u> • Principles of Electronic Biosensors (Purdue Univ.) • Introduction to Bioelectricity (Purdue Univ.) <u>Engineering Principles for Biomimetics: Mechatronics and Photonics</u>

	• Optical Materials and Devices (EPFL) <u>Biomimetics; Sensor and Neuronal Control</u> • Cognitive Neuroscience Robotics – Part A (Osaka Univ.) • Artificial Intelligence (Berkeley)
Acquisition of skills	<u>Biology for Engineers: Molecular and Neuro-Biology</u> The students • Know and understand the fundamentals of molecular biology and neurobiology required for biomimetics • Know and understand the principles of stimulus perception and receptors in nature required for biomimetics (physical, mechanical, electrical. electromagnetic, chemical, etc.) • Know and understand the biological principles and the physiology of sensory organs for orientation required for biomimetics • Have a basic understanding and an overview of biological examples when it comes to stimulus perception and orientation <u>Engineering Principles for Biomimetics: Mechatronics and Photonics</u> The students • Know and understand the fundamentals of mechatronics (in particular data analysis, information processing, circuit engineering, embedded systems and micro-controllers, sensors, etc.) required for biomimetics • Know and understand the fundamentals of photonics (in particular light conductors, micro-optics, micro and nano processing) required for biomimetics <u>Biomimetics; Sensor and Neuronal Control</u> The students • Know and understand the most important examples in the field of bio-inspired sensors and neuronal networks • Are able to describe the biomimetic abstraction process using examples • Are able to critically analyze the sustainability of simple biomimetic applications and their production process Lab • See module Biomimetics Lab 2

Course title	Biology for Engineers: Molecular Biology and Neurobiology
Number of ECTS	3 ECTS
Position in curriculum	2nd semester/module SNC
Teaching & learning methods	Lecture
Examination methods	Examination + assignments
Course content	• Aspects of molecular biology and neurobiology relevant for biomimetics • Aspects of stimulus perception and receptors in nature relevant for biomimetics (physical, mechanical, electrical. electromagnetic, chemical, etc.) • Aspects of sensory organs for orientation (transmission of stim-

	• Working together to create an initial portfolio of biological examples in the category of stimulus perception and orientation • MOOC reflection: - Principles of Electronic Biosensors (Purdue Univ.) - Introduction to Bioelectricity (Purdue Univ.)
Course title	Engineering Principles for Biomimetics: Mechatronics and Photonics
Number of ECTS	3 ECTS
Position in curriculum	2nd semester/module SNC
Teaching & learning methods	Lecture
Examination methods	Examination + assignments
Course content	• Fundamentals of mechatronics (in particular data analysis, information processing, circuit engineering, embedded systems and micro-controllers, sensors, etc.) required for biomimetics • Fundamentals of photonics (in particular light conductors, micro-optics, micro and nano processing) required for biomimetics • Aspects of micro- and nano processing relevant for biomimetics • MOOC reflection: - Optical Materials and Devices (EPFL)
Course title	Biomimetics: Sensor and Neuronal Control
Number of ECTS	3 ECTS
Position in curriculum	2nd semester/module SNC
Teaching & learning methods	Lecture
Examination methods	Examination + assignments
Course content	• Case studies of "bio-inspired sensors and neuronal contro", e.g. - artificial, bio-inspired sensors, self-organization and assembly, digital materials, bio-sensor membranes, sonar, electronic positioning systems; - Neuronal networks, artificial intelligence, simulated annealing, generic algorithms, bio-inspired cognitive systems, highly efficient signal processing, decentral control of intelligent transport systems, swarm intelligence, machine learning, systems analysis and complex systems, stochastic simulation; - Bionic light conductors, reactive materials with integrated sensors, biophotonics, structured paints, artificial compound eyes; • The biomimetic abstraction process using cases from the field of "bio-inspired sensors and neuronal control" • Sustainability of biomimetic applications and their manufacturing processes • MOOC reflection: - Cognitive Neuroscience Robotics – Part A (Osaka Univ.) - Artificial Intelligence (Berkeley)

Module number: **ABT**	Module title: **Anthropo – and Biomedical Technology** (6 ECTS / English)
Study program	**Bio-Inspired Engineering**
Position in curriculum	2nd semester
Categorization	Seventh sub-section of biomimetics (biological, technical, biomimetic and practical basics)
Level	Introduction
Previous knowledge	1st semester
Block course	Yes
Participating students	Study program and certificate students
Contributes to following modules	BL2 as well as all modules of 3rd and 4th semester
Recommended reading	Biology for Engineers: Human Physiology • Boron, Walter F., and Emile L. Boulpaep. Medical physiology. Elsevier Health Sciences, 2016. • Coren, Stanley. Sensation and perception. John Wiley & Sons, Inc., 2003. • Gold, Ben, Nelson Morgan, and Dan Ellis. Speech and audio signal processing: processing and perception of speech and music. John Wiley & Sons, 2011. • Lindsay, Peter H., and Donald A. Norman. Human information processing: An introduction to psychology. Academic Press, 2013. • Marieb, Elaine Nicpon, and Katja Hoehn. Human anatomy & physiology. Pearson Education, 2007. Engineering Principles for Biomimetics: Biomedical Engineering • Bronzino, Joseph D., and Donald R. Peterson. Biomedical engineering fundamentals. CRC Press, 2014. • Helander, Martin G., ed. Handbook of human-computer interaction. Elsevier, 2014. • Ratner, Buddy D., et al. Biomaterials science: an introduction to materials in medicine. Academic press, 2004. • Shortliffe, Edward H., and James J. Cimino. Biomedical informatics. Springer Science+ Business Media, LLC, 2006. Biomimetics: Anthropo – and Biomedical Technology • Breazeal, Cynthia, Kerstin Dautenhahn, and Takayuki Kanda. "Social Robotics." Springer Handbook of Robotics. Springer International Publishing, 2016. 1935-1972. • Kajita, Shuuji, et al. Introduction to humanoid robotics. Vol. 101. Heidelberg: Springer, 2014. • Bekey, George A. Autonomous robots: from biological inspiration to implementation and control. MIT press, 2005. • Webb, Barbara, and Thomas Consilvio. Biorobotics. MIT-Press, 2001.
MOOCs	Biology for Engineers: Human Physiology • Principles of Electronic Biosensors (Purdue) • Introduction to Bioelectricity (Purdue)

	Engineering Principles for Biomimetics: Biomedical Engineering • Cellular Solids 1: Structures, Properties and Engineering Applications (MIT) • Cellular Solids Part 2: Applications in Medicine (MIT) Biomimetics V: Anthropo – and Biomedical Technology • Artificial Intelligence (Berkeley) • Autonomous Mobile Robots (ETH Zurich)
Acquisition of skills	Biology for Engineers: Human Physiology The students • Know and understand the electro- and neurophysiological principles required for biomimetics • Have a deep understanding of the principles of physiology required for biomimetics, e.g. how human sensory organs and biological tissue work • Know and understand the principles of information processing in human beings required for biomimetics • Have a basic understanding and an overview of biological examples when it comes to anthropo- and biomedical technology Engineering Principles for Biomimetics: Biomedical Engineering The students • Know and understand the principles of the human/machine interface required for biomimetics • Know and understand the principles of micro/nanosensors and actuators required for biomimetics • Know and understand the principles of implant and neuroprosthetic technology required for biomimetics Biomimetics Anthropo – and Biomedical Technology The students • Know and understand the most important examples in the field of bio-inspired anthropotechnology and biomedical technology • Are able to describe the biomimetic abstraction process using examples • Are able to critically analyze the sustainability of simple biomimetic applications and their production process Lab • See module Biomimetics Lab 2
Course title	Biology for Engineers: Physiology
Number of ECTS	2 ECTS
Position in curriculum	2nd semester/module ABT
Teaching & learning methods	Lecture
Examination methods	Examination + assignments
Course content	• Aspects of electophysiology and neurophysiology relevant for biomimetics (vital parameters, neuromotor control circuits, electrical processes in biological tissue)

	• Further understanding of the principles of physiology relevant for biomimetics (e.g. how human sensory organs and biological tissue work) • Aspects of information processing in humans relevant for biomimetics • Working together to create an initial portfolio of biological examples in the category of anthropo- and biomedical technology • MOOC reflection: - Principles of Electronic Biosensors (Purdue) - Introduction to Bioelectricity (Purdue)
Course title	Engineering Principles for Biomimetics: Biomedical Engineering
Number of ECTS	2 ECTS
Position in curriculum	2nd semester/module ABT
Teaching & learning methods	Lecture
Examination methods	Examination + assignments
Course content	• Aspects of the human/machine interface relevant for biomimetics • Aspects of biomedical technology relevant for biomimetics, e.g. - Micro & nanosensors (seeing, hearing, smelling, touching, etc.) as well as actuators - Implants and neuroprosthetic technology (artificial retinas, cochlea implants, artificial cochleas, micro electrode arrays, neurochips, electrophysiology, etc.) • MOOC reflection: - Cellular Solids 1: Structures, Properties and Engineering Applications (MIT) - Cellular Solids Part 2: Applications in Medicine (MIT)
Course title	Biomimetics: Anthropo- and Biomedical Technology
Number of ECTS	2 ECTS
Position in curriculum	2nd semester/module ABT
Teaching & learning methods	Lecture
Examination methods	Examination + assignments
Course content	• Case studies of "bio-inspired anthropotechnology and biomedical technology", e.g. - User-friendliness of machine interfaces (design of dials and instruments, airplane cockpit design) - Social robotics (robots to help and take care of people) - Prosthetics, therapeutic approaches, connection of micro electrode arrays and neurochips (e.g. eye-chips) artificial skin/muscle, exo-skeleton - Biomimetic ceramics - Artificial, bio-inspired sensors, neuronal networks, artificial intelligence • The biomimetic abstraction process using cases from the field of "bio-inspired anthropotechnology and biomedical technology" • Sustainability of biomimetic applications and their manufacturing processes • MOOC reflection:

	- Artificial Intelligence (Berkeley) - Autonomous Mobile Robots (ETH Zurich)

Module number: **BL2**	Module title: **Biomimetics Lab 2** (4 ECTS / English)
Study program	**Bio-Inspired Engineering**
Position in curriculum	2nd semester
Categorization	Lab and Practical Application for the modules from the 2nd semester
Level	Introduction
Previous knowledge	BL1, SNC, ABT
Block course	Yes
Participating students	Study program and certificate students
Contributes to following modules	3rd semester
Recommended reading	Simulation and Optimization 2 (using Finite Elements) • Bendsoe, Martin Philip, and Ole Sigmund. Topology optimization: theory, methods, and applications. Springer Science & Business Media, 2013. • Madenci, Erdogan, and Ibrahim Guven. The finite element method and applications in engineering using ANSYS®. Springer, 2015. Imaging Lab 2 • Floreano, Dario, et al., eds. Flying insects and robots. Berlin: Springer, 2010. • Jewel B. Barlow, William H. Rae, Alan Pope. Low-Speed Wind Tunnel Testing. Wiley-Interscience; 3 edition (1999) Rapid Prototyping & Manufacturing 2 • Gershenfeld, Neil. *Fab: the coming revolution on your desk- top--from personal computers to personal fabrication*. Basic Books, 2008. • Pham, Duc, and Stefan S. Dimov. Rapid manufacturing: the technologies and applications of rapid prototyping and rapid tooling. Springer Science & Business Media, 2012. • Venuvinod, Patri K., and Weiyin Ma. Rapid prototyping: la-
MOOCs	none
Acquisition of skills	Simulation and Optimization 2 The students • Know and understand the opportunities of modern simulation and optimization programs in the field of biomimetics • Know and understand the opportunities and limitation of simulation and optimization using finite elements in the field of biomimetics • Are able to simulate and optimize complex simulation and optimization tasks (e.g. aero- and fluid dynamics) from the

	Imaging Lab 2 The students • Know and understand the functioning and importance of a wind tunnel for biomimetics • Know and understand the functioning and importance of a flow channel for biomimetics • Know and understand the functioning and importance of high-speed cameras for biomimetics • Are able to use the abovementioned systems in Fablab to carry out precision measurements and to interpret the results of these measurements Rapid Prototyping & Manufacturing 2 The students • Know and understand the fundamentals, opportunities and limitation of electronic manufacturing in the Electronics Lab • Are able independently to sketch electronic switches, design a circuit board with the support of software (Eagle) and to manufacture the circuit board in the Electronics Lab (cf. Fablab) • Are able independently to implement simple biomimetic prototypes in the Electronic Lab (cf. Fablab) • Know and understand the fundamentals, opportunities and limitation of the Robotics Lab (6-axis robots, Robotic Studio Software, Turtle Robot, ROS) • Are able independently to implement simple biomimetic prototypes in the Electronic Lab (cf. Fablab) Field Trips • Field trips are designed to enable students to deepen and consolidate their ability to analyze from a systematic and macroscopic perspective many biological examples for biomimetics (in particular from the fields of botany and zoology)
Course title	Simulation and Optimization 2
Number of ECTS	1 ECTS
Position in curriculum	2nd semester/module BL2
Teaching & learning methods	Practical exercise
Examination methods	Project BL2 + assignments
Course content	• Modern simulation and optimization programs in the field of biomimetics • Opportunities and limitation of simulation and optimization using finite elements in the field of biomimetics • Simulation and optimization of complex simulation and optimization tasks (e.g. aero- and fluid dynamics) from the field of biomimetics using a finite elements program (Ansys)
Course title	Imaging Lab 2
Number of ECTS	1 ECTS
Position in curriculum	2nd semester/module BL2
Teaching & learning methods	Practical exercise

Examination methods	Project BL2 + assignments
Course content	• Functioning and significance of wind tunnels, flow channels and high-speed cameras for biomimetics • Introduction on how to safely use the abovementioned systems in the Fablab - simple measurements and interpretation of the results
Course title	Rapid Prototyping & Manufacturing 2
Number of ECTS	2 ECTS
Position in curriculum	2nd semester/module BL2
Teaching & learning methods	Practical exercise
Examination methods	Project BL2 + assignments
Course content	• Fundamentals, opportunities and limitations of electronic manufacturing in the Electronics Lab • Sketching simple electronic switches, computer-supported design of printed circuit boards using Eagle, production of a fully functioning circuit board in the Electronics Lab (cf. Fablab) • Incorporation of the printed circuit boards into a simple but fully functioning biomimetic prototype • Fundamentals, opportunities and limitations of the Robotics Lab (6-axis robots, Robotic Studio Software, Turtle Robot, ROS) • Manufacturing of simple mimetic prototypes in the Robot-

3.4.3 Semester 3

Module number: **BIN**	Module title: **Bio-Inspired Innovation** (8 ECTS / English)
Study program	**Bio-Inspired Engineering**
Position in curriculum	3rd semester
Categorization	Sustainable technical implementation
Level	Introduction
Previous knowledge	ITB, BSI
Block course	Yes
Participating students	Study program and certificate students
Contributes to following modules	All modules of the 3rd and 4th semester

Recommended reading	Technology and Innovation Management • BurgeSmani, Robert A., and Steven C. Wheelwright. "Stra- tegic management of technology and innovation." READING 1.1 (2004). • Drucker, Peter. Innovation and entrepreneurship. Routledge, 2014. • James, Utterback. "Mastering the Dynamics of Innovation." Harvard Business School Press, Boston (1994). • Prahalad, Coimbatore Krishna, and Mayuram S. Krishnan. The new age of innovation: Driving cocreated value through global networks. McGraw Hill Professional, 2008. Product Development & Business Plan • Christensen, Clayton. The innovator's dilemma: when new technologies cause great firms to fail. Harvard Business Re- view Press, 2013. • Leifer, Richard. Radical innovation: How mature companies can outsmart upstarts. Harvard Business Press, 2000. • Mullins, John Walker, and Randy Komisar. Getting to plan B: Breaking through to a better business model. Harvard Business Press, 2009. • Sahlman, William Andrews. How to write a great business plan. Harvard Business Press, 2008. • Trott, Paul. Innovation management and new product development. Pearson education, 2008. Sustainable Fabrication of bio-inspired Products • Ariga, Katsuhiko, et al. "Challenges and breakthroughs in recent research on self-assembly." Science and Technology of Advanced Materials (2016). • Brodie, Ivor, and Julius J. Muray. The physics of mi- cro/nano-fabrication. Springer Science & Business Media, 2013. • Chryssolouris, George. Manufacturing systems: theory and practice. Springer Science & Business Media, 2013. • Dahmus, Jeffrey B., and Timothy G. Gutowski. "An envi- ronmental analysis of machining." ASME 2004 international
	mechanical engineering congress and exposition. American Society of Mechanical Engineers, 2004.
MOOCs	Product Development & Business Plan • Becoming an Entrepreneur (MIT) Sustainable Fabrication of bio-inspired Products • Fundamentals of Manufacturing Processes (MIT) • Micro and Nanofabrication (EPFL)

Acquisition of skills	Technology and Innovation Management The students • Know and understand the most important terms, concepts, statistics and fundamentals of technology and innovation management • Know and understand the best practice in technology and innovation management (stage gate process, TE process, spiral development process, risk and portfolio management, etc.) and are able to apply these on their own to biomimetic projects • Know and understand the challenges and trends of technology and innovation management (fuzzy front end, innovation dilemma, gate weighting, technology push, etc.) and are able to apply these on their own to biomimetic projects Product Development The students • Know and understand the most important terms, concepts, statistics and fundamentals of product development • Know and understand the best practice in product development (further knowledge of stage gate and TE process, risk and portfolio management, etc.) and are able to apply these on their own to biomimetic projects • Know and understand the challenges and trends of product development (open innovation, design thinking, customer co-creation, etc.) and are able to apply these on their own to biomimetic projects • Know and understand the most important components of a business plan (product and company idea, market and competition, financial plan, risk assessment, etc.) • Are able on their own to develop and present a business plan with all necessary components for a bio-inspired product idea ("pitching") Sustainable Fabrication of Bio-Inspired Products The students • Know and understand the most important fundamentals of rapid prototyping, manufacturing & tooling for biomimetics (e.g. tissue engineering, bio printing, two photon absorption, metal laser melting, etc.), their opportunities and limitations • Know and understand the most important fundamentals of modern manufacturing techniques for biomimetics (e.g.
	micro and nano fabrication, self-assembly, etc.) and their sustainability as well as their opportunities and limitations • Are able to critically evaluate and judge the technological feasibility and sustainability of implementing a bio-inspired product idea on a large scale
Course title	Technology and Innovation Management
Number of ECTS	2 ECTS

Position in curriculum	3rd semester/module BSI
Teaching & learning methods	Lecture
Examination methods	Module examination + assignments
Course content	• Terms, concepts, statistics and fundamentals of technology and innovation management • Best practice in technology and innovation management (stage gate process, TE process, spiral development process, risk and portfolio management, etc.) • Independent application of best practice to biometric projects (case study reflection) • Challenges and trends of technology and innovation management (fuzzy front end, innovation dilemma, gate weighting, technology push, etc.) • Independent application to biomimetics (case study reflection)
Course title	Product Development
Number of ECTS	2 ECTS
Position in curriculum	3rd semester/module BSI
Teaching & learning methods	Lecture
Examination methods	Module examination + assignments
Course content	• Important terms, concepts, statistics and fundamentals of product development • Best practice in product development (further knowledge of stage gate and TE process, risk and portfolio management, etc.) • Challenges and trends of product development (open innovation, design thinking, customer co-creation, etc.) • Independent application to biomimetic projects (case study reflection) • Components of a business plan (product and company idea, market and competition, financial plan, risk assessment, etc.) • Develop a complete business plan for a biomimetic product idea • Present ("elevator speech", "pitching") own bio-inspired product idea as part of the module Business Plan Competition • MOOC reflection "Becoming an Entrepreneur" (MIT)
Course title	Sustainable Fabrication of bio-inspired Products
Number of ECTS	3 ECTS
Position in curriculum	3rd semester/module BSI
Teaching & learning methods	Lecture
Examination methods	Module examination + assignments

Course content	• Fundamentals, opportunities, limitations and sustainability of rapid prototyping, manufacturing and tooling for biomimetics (e.g. tissue engineering, bio-printing, two-photon absorption, metal laser melting, etc.) • Fundamentals, opportunities, limitations and sustainability of modern manufacturing techniques and processes for biomimetics (e.g. micro and nano fabrication, self-assembly, etc.) • Critical analysis (case studies) to evaluate the technological feasibility and sustainability of large-scale implementation of bio-inspired product ideas • MOOCs reflection: - Fundamentals of Manufacturing Processes (MIT) - Micro and Nanofabrication (EPFL)

Module number: **PAP**	Module title: **Procedures & Processes** (8 ECTS / English)
Study program	**Bio-Inspired Engineering**
Position in curriculum	3rd semester
Categorization	Eighth sub-section of biomimetics (biological, technical, biomimetic and practical basics)
Level	Introduction
Previous knowledge	1st and 2nd semester
Block course	Yes
Participating students	Study program and certificate students
Contributes to following modules	BL3 and all modules in 4th semester
Recommended reading	Biology for Engineers: Micro-, Molecular and Synthetic Biology • Gerard J. Tortora and Berdell R. Funke. Microbiology: An Introduction. Pearson; 12 edition (January 10, 2015) • Lambers, Hans, F. Stuart Chapin III, and Thijs L. Pons. "Photosynthesis." Plant physiological ecology. Springer New York, 2008. 11-99. • Schmidt, Markus, ed. Synthetic biology: industrial and environmental applications. John Wiley & Sons, 2012. Siegelbaum, Steven A., and A. J. Hudspeth. Principles of neural science. Eds. Eric R. Kandel, James H. Schwartz, and Thomas M. Jessell. Vol. 4. New York: McGraw-hill, 2000. Engineering Principles for Biomimetics: Applied Micro- and Nano- technology; Bio-Technology & Chemistry • Buchanan, Bob B., Wilhelm Gruissem, and Russell L. Jones, eds. Biochemistry and molecular biology of plants. John Wiley & Sons, 2015. • Harborne, Jeffrey B. Introduction to ecological biochemistry. Academic Press, 2014. • Prasad, Paras N. Introduction to biophotonics. John Wiley & Sons, 2004.

	• Rawlings, Douglas E., ed. Biomining: theory, microbes and industrial processes. Springer Science & Business Media, 2013. • William J. Thieman, Michael A. Palladino. Introduction to Biotechnology. 3 edition (2012). <u>Biomimetics VI: Procedures and Processes in Nature</u> • Ariga, Katsuhiko, et al. "Challenges and breakthroughs in recent research on self-assembly." Science and Technology of Advanced Materials (2016). • Bianco-Peled, Havazelet, and Maya Davidovich-Pinhas, eds. Bioadhesion and biomimetics: from nature to applications. CRC Press, 2015. • Binder, Wolfgang H., ed. Self-healing polymers: from prin- ciples to applications. John Wiley & Sons, 2013. • Floreano, Dario, and Claudio Mattiussi. Bio-Inspired artificial intelligence: theories, methods, and technologies. MIT press, 2008. • Gratzel, Michael, ed. Energy resources through photochemistry and catalysis. Elsevier, 2012. • Bhushan, Bharat. Biomimetics: bioinspired hierarchical- structured surfaces for green science and technology. Springer, 2016.
MOOCs	<u>Biology for Engineers: Micro-, Molecular and Synthetic Biology</u> • Principles of Synthetic Biology (MIT) <u>Engineering Principles for Biomimetics VI: Applied Micro- and Nano-technology; Bio-Technology & Chemistry</u> • Principles of Biochemistry (Harvard) • Micro and Nanofabrication (MEMS) by EPFL

Acquisition of skills	<u>Biology for Engineers: Micro-, Molecular and Synthetic Biology</u>
	The students
	• Know and understand the fundamentals of the following for procedures and processes taking place in nature
	- microbiology
	- molecular biology
	- synthetic biology
	• Are therefore able to clearly explain and describe the main procedures and processes taking place in nature, e.g.
	  o Bioenergetics (photosynthesis; recycling, avoiding landfill material)
	  o Micro and nano structured biological surface effects - adhesive, non-adhesive, antifouling, self-cleaning, resistance reduction)
	  o Structuring hierarchies
	  o Processes to produce energy-rich surfaces
	  o Energy-minimization principle
	  o Filters and membranes, fog collectors
	  o Self-healing, cleaning and assembly
	  o Bio-communication
	  o Targeted Genome Editing CRISPR/Cas9
	
	<u>Engineering Principles for Biomimetics: Applied Micro- and Nano- technology; Bio-Technology & Chemistry</u>

	The students
	• Know and understand the necessary fundamentals for procedures and processes taking place in nature in the fields of
	  o Applied micro-technology and nano-technology
	  o Biotechnology and
	  o Biochemistry
	• Are therefore able to clearly explain and describe the main procedures and processes taking place in nature, e.g.
	  o Interactions between atoms and molecules
	  o Adhesion, surface tension, surface roughness, surface energy, contact theory
	  o Micro and nano mechanics and tribology
	  o Micro-cracks and crack formation
	  o Hydrogen technology
	  o Self-aggregation, self-assembly
	  o Micro and nano optics / photonics
	  o Micro and nano structuring and coating
	
	<u>Biomimetics Procedures and Processes in Nature</u>
	The students
	• Know and understand the most important examples in the field of bio-inspired procedures and processes
	• Are able to describe the biomimetic abstraction process using examples
	• Are able to critically analyze the sustainability of simple biomimetic applications and their production process

Course title	Biology for Engineers: Micro-, Molecular and Synthetic Biology
Number of ECTS	3 ECTS
Position in curriculum	3rd semester/module PAP
Teaching & learning methods	Lecture
Examination methods	Examination, assignments
Course content	• Which techniques are used in nature to control processes - e.g. organic bioenergetics such as photosynthesis • Fundamentals of procedures and processes taking place in nature in the fields of - microbiology - molecular biology - synthetic biology • Describe and understand the main procedures and processes taking place in nature, e.g. - Bioenergetics (photosynthesis; recycling, avoiding landfill material) - Micro and nano structured biological surface effects - adhesive, non-adhesive, antifouling, self-cleaning, resistance reduction) - Structuring hierarchies - Processes to produce energy-rich surfaces - Energy-minimization principle - Filters and membranes, fog collectors - Self-healing, cleaning and assembly - Growth

	- Energy and industrial crops - Bio-communication - Targeted Genome Editing CRISPR/Cas9 • MOOC reflection "Principles of Synthetic Biology" (MIT)
Course title	Engineering Principles for Biomimetics: Applied Micro and Nano- technology, Bio-Technology & Chemistry
Number of ECTS	3 ECTS
Position in curriculum	3rd semester/module PAP
Teaching & learning methods	Lecture
Examination methods	Examination, assignments
Course content	• Procedures and processes in nature: Scientific fundamentals of applied micro-technology and nano-technology, biotechnology, and biochemistry • Procedures and processes in nature: - Interactions between atoms and molecules - Adhesion, surface tension, surface roughness, surface energy, contact theory - Micro and nano mechanics and tribology - Micro-cracks and crack formation - Hydrogen technology - Self-aggregation, self-assembly - Micro and nano optics / photonics - Micro and nano structuring and coating • MOOC reflection "Principles of Synthetic Biology" (MIT) - Principles of Biochemistry (Harvard) - Micro and Nanofabrication (MEMS) by EPFL
Course title	Biomimetics: Procedures and Processes in Nature
Number of ECTS	2 ECTS
Position in curriculum	3rd semester/module PAP
Teaching & learning methods	Lecture
Examination methods	Examination, assignments
Course content	- Important examples in the field of bio-inspired procedures and processes: Understanding, abstracting and applying - Bio-inspired procedures and processes – sustainability of biomimetic applications and their manufacturing processes

Module number: **EAO**	Module title: **Evolution & Optimization** (6 ECTS / English)
Study program	**Bio-Inspired Engineering**
Position in curriculum	3rd semester
Categorization	Ninth sub-section of biomimetics (biological, technical, biomimetic and practical basics)
Level	Introduction
Previous knowledge	1st and 2nd semester
Block course	Yes
Participating students	Study program and certificate students
Contributes to following modules	BL3 and all modules in 4th semester
Recommended reading	<u>Biology for Engineers: Theoretical and Evolutionary Biology, Self- Assembly and Molecular Machines</u> **Ad Theoretical Biology** • Callebaut, Werner. "Modularity: Understanding the Devel- opment and Evolution of Natural Complex Systems (Vienna Series in Theoretical Biology)." (2005). **Ad Evolutionary-Biology** • Beyer, Hans-Georg. The theory of evolution strategies. Springer Science & Business Media, 2013. • Ernst Mayr: The Growth of Biological Thought. Diversity, Evolution, and Inheritance. Harvard University Press, Cam- bridge, Massachusetts (1982). **Self-Assembly & Molecular Machines** • Balzani, Vincenzo, Venturi, Margherita and Credi, Alberto. Molecular devices and machines: a journey into the nan- oworld. John Wiley & Sons, 2006. • Pelesko, J.A., (2007) Self Assembly: The Science of Things That Put Themselves Together, Chapman & Hall/CRC Press. <u>Engineering Principles for Biomimetics: Mathematical Biology & Applied Computer Sciences</u> **Mathematical Biology** • Britton, Nicholas. Essential mathematical biology. Springer Science & Business Media, 2012. • Prusinkiewicz, P. & Lindenmeyer, A. 1990. The Algorithmic Beauty of Plants. Berlin: Springer-Verlag. **Applied Computer Sciences** • Bendsoe, Martin Philip, and Ole Sigmund. Topology optimi- zation: theory, methods, and applications. Springer Science & Business Media, 2013. • Brackett, D., I. Ashcroft, and R. Hague. "Topology optimization for additive manufacturing." Proceedings of the Solid Freeform Fabrication Symposium, Austin, TX. 2011. <u>Biomimetics Evolution and Optimization</u>

	• Bendsoe, Martin Philip, and Ole Sigmund. Topology optimi- za-tion: theory, methods, and applications. Springer Science & Business Media, 2013. • Dasgupta, Dipankar, and Zbigniew Michalewicz, eds. Evolu-tionary algorithms in engineering applications. Springer Sci-ence & Business Media, 2013. • Michalski, Ryszard S., Jaime G. Carbonell, and Tom M. Mitchell, eds. Machine learning: An artificial intelligence ap- proach. Springer Science & Business Media, 2013. • Simon, Dan. Evolutionary optimization algorithms. John Wiley & Sons, 2013.
MOOCs	<u>Biology for Engineers: Theoretical and Evolutionary Biology, Self- As-sembly and Molecular Machines</u> • Principles of Synthetic Biology (MIT) • Introduction to Systems Biology (IEEE) <u>Engineering Principles for Biomimetics: Mathematical Biology & Ap-plied Computer Sciences</u> • Introduction to Computer Science and Programming Using Py-thon (MIT) • Hands-on Introduction to Engineering Simulations (Cornell) <u>Biomimetics: Evolution and Optimization</u> • Cellular Solids 1,3: Structures, Properties and Engineering Ap-plications (MIT)
Acquisition of skills	<u>Biology for Engineers: Theoretical and Evolutionary Biology, Self- As-sembly and Molecular Machines</u> The students • Know and understand the fundamentals of theoretical biology required for biomimetics - i.e. the basic formal models to de-scribe biological phenomema (dynamics of living systems) • Know and understand the fundamentals of evolutionary biol-ogy required for biomimetics • Know and understand the fundamentals of self-assembly re-quired for biomimetics • Know and understand the fundamentals of molecular ma-chines required for biomimetics • Are able to clearly explain and describe the abovementioned fundamentals of these 4 sub-fields of biomimetics <u>Engineering Principles for Biomimetics: Mathematical Biology & Ap-plied Computer Sciences</u> • Know and understand the fundamentals of mathematical biol-ogy required for biomimetics • Know and understand the fundamentals of applied infor-mation technology required for biomimetics • Are able to use the abovementioned fundamentals of mathe-matical biology and applied information technology for a soft-ware application <u>Biomimetics Evolution and Optimization</u> The students • Know and understand the most important bio-inspired ex-amples in the field of evolution and optimization • Are able to describe the biomimetic abstraction process using examples

	• Are able to critically analyze the sustainability of simple biomimetic applications and their production process
Course title	Biology for Engineers: Theoretical and Evolutionary Biology, Self- Assembly and Molecular Machines
Number of ECTS	2 ECTS
Position in curriculum	3rd semester/module EAO
Teaching & learning methods	Lecture
Examination methods	Examination, assignments
Course content	• The principle of biological evolution • Fundamentals of theoretical biology for biomimetics - Fundamental formal models to describe biological phenomena (dynamics of living systems) - Evolutionary stable systems - Replicator equations • Fundamentals of self-assembly and self-optimization in biological systems • Fundamentals of molecular machines • Are able to clearly explain and describe the abovementioned fundamentals of these 4 sub-fields of biomimetics • MOOC reflection - Principles of Synthetic Biology (MIT) - Introduction to Systems Biology (IEEE)
Course title	Engineering Principles for Biomimetics: Mathematical Biology & Applied Computer Sciences
Number of ECTS	2 ECTS
Position in curriculum	3rd semester/module EAO
Teaching & learning methods	Lecture
Examination methods	Examination, assignments
Course content	• Fundamentals of mathematical biology and of applied information technology for biomimetics: - Evolutionary algorithms - Soft kill option method (topology optimization) - Computer aided optimization (design optimization) - Simulated annealing - Artificial intelligence • Application of algorithms - Pseudo code, structogram, program process plan • MOOC reflection - Introduction to Computer Science and Programming Using Python (MIT) - Hands-on Introduction to Engineering Simulations (Cornell)
Course title	Biomimetics: Evolution and Optimization
Number of ECTS	2 ECTS
Position in curriculum	3rd semester/module EAO
Teaching & learning methods	Lecture
Examination methods	Examination, assignments
Course content	• Biomimetic examples in the field of evolution and optimization - Evolution technology and strategy - Structure, topology and design optimization (preventing voltage peaks, reducing weight, etc.) - Reducing notch stress, etc.

Module number: **BL3**	Module title: **Biomimetics Lab 3** (8 ECTS / English)
Study program	**Bio-Inspired Engineering**
Position in curriculum	3rd semester
Categorization	Lab and Practical Application for modules from the 3rd semester
Level	Introduction
Previous knowledge	Modules of the 3rd semester
Block course	Yes
Participating students	Study program and certificate students
Contributes to following modules	All modules in the 4th semester
Recommended reading	Imaging Lab 3 • Egerton, Ray F. Physical principles of electron microscopy: an introduction to TEM, SEM, and AEM. Springer Science & Business Media, 2nd edition (2016). • Mertz, Jerome. Introduction to Optical Microscopy. W. H. Freeman; 1st edition (2009). • Robinson, David G., et al. Methods of preparation for electron microscopy: an introduction for the biomedical sciences. Springer Science & Business Media, 2012. • Werner Nachtigall. Exploring with the Microscope (A Book of Discovery & Learning). Sterling (1997) Programming Lab • Lutz, Mark. Learning python. "O'Reilly Media, Inc.", 2013. • Stevens, Tim J., and Wayne Boucher. Python Programming for Biology. Cambridge University Press, 2015. • Back, Thomas. Evolutionary algorithms in theory and practice: evolution strategies, evolutionary programming, genetic algorithms. Oxford university press, 1996. • Bendsoe, Martin Philip, and Ole Sigmund. Topology optimization: theory, methods, and applications. Springer Science & Business Media, 2013. • Cormen, Thomas H. *Introduction to algorithms*. 3rd edition, MIT press, 2009. • Haupt, Randy L., and Sue Ellen Haupt. Practical genetic algorithms. John Wiley & Sons, 2004. • Madenci, Erdogan, and Ibrahim Guven. The finite element method and applications in engineering using ANSYS®.

	Springer, 2015. • Mitchell, Melanie. An introduction to genetic algorithms. MIT press, 1998. Simulation and Optimization 3 (using finite elements) • Bendsoe, Martin Philip, and Ole Sigmund. Topology optimization: theory, methods, and applications. Springer Science & Business Media, 2013. • Madenci, Erdogan, and Ibrahim Guven. The finite element method and applications in engineering using ANSYS®. Springer, 2015. • Strang, Gilbert, and George J. Fix. An analysis of the finite element method. Vol. 212. Englewood Cliffs, NJ: Prentice-hall, 1973. • Zienkiewicz, Olgierd Cecil, et al. The finite element method. Vol. 3. London: McGraw-hill, 1977. Rapid Prototyping & Manufacturing 3 • Gershenfeld, Neil. *Fab: the coming revolution on your desk- top--from personal computers to personal fabrication*. Basic Books, 2008. • Pham, Duc, and Stefan S. Dimov. Rapid manufacturing: the technologies and applications of rapid prototyping and rapid tooling. Springer Science & Business Media, 2012. • Venuvinod, Patri K., and Weiyin Ma. Rapid prototyping: laser-based and other technologies. Springer Science & Business Media, 2013.
MOOCs	Programming Lab • Introduction to Computer Science and Programming using Python (MIT) • Introduction to Computer Science (Harvard) Simulation and Optimization 3 (using finite elements) • Introduction to Computational Thinking and Data Science (Harvard) • Hands-on Introduction to Engineering Simulations (Cornell)
Acquisition of skills	Imaging Lab 3 The students • Further expand their knowledge gained in Imaging Lab 1 when it comes to the functioning, use, opportunities, limitation and preparation methods for the main analytical imaging techniques (light microscope, 3D microscope, REM, micro CT, MRI, ultrasound) • Are able to work independently using the abovementioned techniques (e.g. 3D light microscope, REM, micro CT) • Are able to carry out, document and analyze geometrics using these techniques based on examples dealt with in the modules - ***Bio-Inspired Innovation*** - ***Procedures and Processes*** - ***Evolution & Optimization*** . Programming Lab (using Python) The students

	• Know and understand the fundamentals of object-oriented programming • Know and understand the fundamentals of programming with Python • Know and understand the fundamentals of "Biopython" • Are able on their own to write small-scale optimization programs in Python using generic algorithms Simulation and Optimization 3 (using Finite Elements) The students • Know and understand the opportunities of modern simulation and optimization programs in the fields of biomimetics and have a deep understanding of the specific areas "Procedures and Processes" and "Evolution and Optimization". • Know and understand the opportunities of modern simulation and optimization programs in the fields of biomimetics and have a deep understanding of the specific area "Sustainable Manufacturing of Biomimetic Products". • Know and understand the opportunities and limitation of simulation and optimization using finite elements in the abovementioned fields • Are able to simulate and optimize complex simulation and optimization tasks from the abovementioned fields on their own using a finite elements program (Ansys). Rapid Prototyping & Manufacturing 3 The students • Know and understand the opportunities of digital and additive manufacturing for developing biomimetic products. • Know and understand the opportunities of digital and additive manufacturing for sustainable production of biomimetic products. • Are able to independently produce and test biomimetic prototypes in Fablab – in particular for the modules - ***Bio-Inspired Innovation*** - ***Procedures and Processes*** - ***Evolution & Optimization***
Course title	Imaging Lab 3
Number of ECTS	2 ECTS
Position in curriculum	3rd semester module/BL3
Teaching & learning methods	Practical exercise, eLearning
Examination methods	Project BL3 + assignments
Course content	• Lab exercises with light microscope, 3D microscope, REM, micro CT, OCT, MRI, ultrasound using examples from the modules in semester 3 - ***Bio-Inspired Innovation*** - ***Procedures and Processes*** - ***Evolution & Optimization*** • Lab exercises to generate and record relevant digital ge-

	using examples from the modules in semester 3 as well as analysis, interpretation, documentation and presentation of these geometrics • Lab exercises/project
Course title	Programming Lab (Using Python)
Number of ECTS	2 ECTS
Position in curriculum	3rd semester module/BL3
Teaching & learning methods	Practical exercise, eLearning
Examination methods	Project BL3 + assignments
Course content	• Fundamentals of object-oriented programming • Fundamentals of programming with Python • Fundamentals of "Biopython" • Independent programming of small-scale optimization programs (process, topology and design optimization) on the basis of generic algorithms using Python • MOOCs reflection: - Introduction to Computer Science and Programming using Python (MIT) - Introduction to Computer Science (Harvard)
Course title	Simulation and Optimization 3 (using Finite Elements)
Number of ECTS	2 ECTS
Position in curriculum	3rd semester module/BL3
Teaching & learning methods	Practical exercise, eLearning
Examination methods	Project BL3 + assignments
Course content	• Exercises on the opportunities offered by modern simulation and optimization programs in the field of biomimetics – in particular for the areas "Procedures and Processes" and "Evolution and Optimization". • Exercises on the opportunities offered by modern simulation and optimization programs in the field of biomimetics – in particular for the areas "Procedures and Processes" and "Evolution and Optimization". • Independent optimization/simulation using a finite element program (Ansys) – solving complex simulation and optimization tasks in the abovementioned areas • MOOCs reflection - Introduction to Computational Thinking and Data Science (Harvard) - Hands-on Introduction to Engineering Simulations (Cornell)
Course title	Rapid Prototyping & Manufacturing 3
Number of ECTS	2 ECTS
Position in curriculum	3rd semester module/BL3
Teaching & learning methods	Practical exercise, eLearning
Examination methods	Project BL3 + assignments
Course content	• Lab exercises Opportunities of digital and additive manufacturing for developing biomimetic products. • Lab exercises Opportunities of digital and additive manufacturing for sustainable production of biomimetic products. • Lab exercises to independently produce and test biomimetic prototypes - in particular for the modules - *Bio-Inspired Innovation*

	- *Procedures and Processes* - *Evolution & Optimization*

3.4.4 Semester 4

Module number: **SAO**	Module title: **Systemics and Organization** (6 ECTS / English)
Study program	**Bio-Inspired Engineering**
Position in curriculum	4th semester
Categorization	Tenth sub-section of biomimetics (biological, technical, biomimetic and practical basics)
Level	Introduction
Previous knowledge	1st, 2nd and 3rd semester
Block course	Yes
Participating students	Study program and certificate students
Contributes to following modules	**BL4**

Recommended reading	Biology for Engineers: Systemics and Organization • Camazine, Scott. Self-organization in biological systems. Princeton University Press, 2003. • Grime, J. Philip. Plant strategies, vegetation processes, and ecosystem properties. John Wiley & Sons, 2006. • Kennedy, James, et al. Swarm intelligence. Morgan Kauf- mann, 2001. Engineering Principles for Biomimetics: Systems Engineering and Cybernetics • Davis, Don, and Eugene Patronis. Sound system engineer- ing. CRC Press, 2014. • Pedrycz, Witold, and Fernando Gomide. Fuzzy systems en- gineering: toward human-centric computing. John Wiley & Sons, 2007. • Von Foerster, Heinz. Understanding understanding: Essays on cybernetics and cognition. Springer Science & Business Media, 2007. • Wiener, Norbert. Cybernetics or Control and Communication in the Animal and the Machine. Vol. 25. MIT press, 1961. Biomimetics Systemics und Organization • Berkes, Fikret, Carl Folke, and Johan Colding. Linking social and ecological systems: management practices and social mechanisms for building resilience. Cambridge University Press, 2000. • Haefner, James W., ed. Modeling biological systems: principles and applications. Springer Science & Business Media, 2012. • Hannon, Bruce, and Matthias Ruth. "Modeling dynamic bio- logical systems." Modeling dynamic biological systems. Springer International Publishing, 2014. 3-28. • Lesk, Arthur. Introduction to bioinformatics. Oxford University Press, 2013. • Malik, Fredmund. Strategy: Navigating the Complexity of the New World. Vol. 3. Campus Verlag, 2013.
MOOCs	Biology for Engineers: Systemics and Organization • Introduction to Systems Biology (IEEE) • Circular Economy: An Introduction (TU Delft) Engineering Principles for Biomimetics: Systems Engineering and Cybernetics • Nature, in Code: Biology in JavaScript (EPFL) Biomimetics Systemics und Organization • Artificial Intelligence (Berkeley) • Cognitive Neuroscience Robotics – Part A (Osaka University)

Acquisition of skills	<u>Biology for Engineers: Systemics and Organization</u> The students • Know and understand the fundamentals of biological systems and organization forms required for biomimetics - - of ecosystems and environmental ecology - of the central nervous system - of communication • Know and understand the main strategies of nature for managing complexity required for biomimetics • Are able to correctly desribe the abovementioned methods and processes in their own words <u>Engineering Principles for Biomimetics: Systems Engineering and Cybernetics</u> The students • Know and understand the most important fundamentals for biomimetics of - cybernetics - systems theory - systems engineering • Are able to correctly desribe the abovementioned methods and processes in their own words <u>Biomimetics Systemics und Organization</u> The students • Know and understand the most important examples in the field of bio-inspired systems and organizations • Are able to describe the biomimetic abstraction process using examples • Are able to critically analyse the sustainability of simple bio-
Course title	Biology for Engineers: Systemics and Organization
Number of ECTS	2 ECTS
Position in curriculum	4th semester/module SAO
Teaching & learning methods	Lecture
Examination methods	Examination, assignments
Course content	• Fundamentals of - biological systems and organization forms
	- ecosystems and environmental ecology - of the central nervous system - of communication Further topics: Self-organization, colonial insects (bees, termites, ants, etc.), swarm behavior and swarm intelligence, networked thinking • Fundamentals of natural strategies for managing complexity • Correct description of the abovementioned methods and processes • MOOC reflection: - Introduction to Systems Biology (IEEE) - Circular Economy: An Introduction (TU Delft)
Course title	Engineering Principles for Biomimetics: Systems Engineering and Cybernetics
Number of ECTS	2 ECTS

Position in curriculum	4th semester/module SAO
Teaching & learning methods	Lecture
Examination methods	Examination, assignments
Course content	• Fundamentals of - cybernetics - systems theory - systems engineering • Correct description of the abovementioned methods and processes • MOOC reflection: - Nature, in Code: Biology in JavaScript (EPFL)
Course title	Biomimetics: Systemics und Organization
Number of ECTS	2 ECTS
Position in curriculum	4th semester/module SAO
Teaching & learning methods	Lecture
Examination methods	Examination, assignments
Course content	• Examples in the field of bio-inspired systems and organizations • The biomimetic abtraction process using examples in the field of bio-inspired systems and organizations • Critical analysis of the sustainability of biomimetic applications and their manufacturing processes in the field of bio-inspired systems and organizations • MOOC reflection: - Artificial Intelligence (Berkeley) - Cognitive Neuroscience Robotics – Part A (Osaka University)

Module number: **BL4**	Module title: **Biomimetics Lab 4** (6 ECTS / English)
Study program	**Bio-Inspired Engineering**
Position in curriculum	4th semester
Categorization	Lab and Practical Application for the modules in the 4th semester
Level	Advanced students
Previous knowledge	BL1-3, modules in the first 3 semesters
Block course	Yes
Participating students	Study program and certificate students
Contributes to following modules	Master thesis
Recommended reading	Option 1: How to *make* (almost) anything (together with MIT FabAcademy / CRI-Fablab / additional Fablabs) • Gershenfeld, Neil. "*How to make almost anything: The digital fabrication revolution*." Foreign Aff. 91 (2012): 43. • Gershenfeld, Neil. *Fab: the coming revolution on your desk- top--from personal computers to personal fabrication*. Basic Books, 2008. • FabAcademy: http://fabacademy.org/ Option 2: How to grow (*almost*) anything (together with MIT FabAcademy / Harvard Medical School / CRI-Fablab / additional Fablabs) • HTGAA – the Bio Academy 2016 by George Church, Harvard Medical School: http://bio.academany.org/ • Church, George M., and Ed Regis. Regenesis: how synthetic biology will reinvent nature and ourselves. Basic Books, 2014. • Palsson, Bernhard. Systems biology. Cambridge university press, 2015. Option 3: Field Trip "The Rainforest of the Austrians" (Costa Rica) • Gebeshuber, Ille C., and Mark O. MacQueen. "What is a physicist doing in the jungle? Biomimetics of the rainforest." Applied Mechanics and Materials. Vol. 461. Trans Tech Pub- lications, 2014. • Grime, J. Philip. Plant strategies, vegetation processes, and ecosystem properties. John Wiley & Sons, 2006. • Sánchez-Azofeifa, G. Arturo, et al. "Integrity and isolation of Costa Rica's national parks and biological reserves: examining the dynamics of land-cover change." Biological Conservation 109.1 (2003): 123-135.
MOOCs	Option 1: How to *make* (almost) anything (together with MIT FabAcademy and the CRI-Fablab) • Mechanical Behavior of Materials Part 1-3 (MIT) • Cellular Solids 1 Part 1-3 (MIT) Option 2: How to grow (*almost*) anything (together with MIT FabAcademy / Harvard Medical School / CRI-Fablab / additional Fablabs) • Principles of Synthetic Biology (MIT) • Introduction to Systems Biology (IEEE)

Acquisition of skills	Option 1: How to *make* (almost) anything (together with MIT Fab Academy and the CRI-Fablab & additional Fablabs) The students • Know and understand the process of digital manufacturing - from the initial idea via rapid prototyping to documentation • Know and understand the opportunities of digital manufacturing • Know and understand the main digital coding formats and their implementation for physical objects • Are able on their own to make a range of bio-inspired prototypes using a selection of digital devices in Fablab Option 2: How to grow (*almost*) anything (together with MIT Fab Academy/Harvard Medical School/CRI-Fablab & additional Fablabs) The students • Know and understand important experimental fundamentals of synthetic biology • Are able to carry out independently basic synthetic biology experiments in Fablab Option 3: Field Trip “The Rainforest of the Austrians” (Costa Rica) The students • Are able to systematically analyze and observe a wide range of natural biological examples • Know and understand the principles of biological fieldwork • Are able to carry out, document and interpret planned experiments in real-life field conditions
Course title	Option 1: How to make (almost) anything (together with MIT Fab Academy, the CRI-Fablab & additional Fablabs)
Number of ECTS	6 ECTS
Position in curriculum	4th semester module/BL4
Teaching & learning methods	Practical exercise, eLearning
Examination methods	Project BL4 + assignments (also possible in connection with Master thesis)
Course content	• principles and practices, project management • computer-aided design • computer-controlled cutting • electronics production • 3D scanning and printing • electronics design • computer-controlled machining • embedded programming • mechanical design • machine design • input devices • molding and casting • output devices • composites

Course title	Option 2: How to grow (almost) anything (together with MIT Fab Academy/Harvard Medical School/CRI-Fablab/additional Fablabs)
Number of ECTS	6 ECTS
Position in curriculum	4th semester module/BL4
Teaching & learning methods	Practical exercise, eLearning
Examination methods	Project BL4 + assignments (also possible in connection with Master
Course content	• Principles and Practices • Tool Chains
Course title	• UE Option 3: Field Trip "Costa Rica: the Rainforest of the Austrians"
Number of ECTS	6 ECTS
Position in curriculum	4th semester module/BL4
Teaching & learning methods	Practical exercise, eLearning
Examination methods	Project BL4 + assignments (also possible in connection with Master
Course content	• Formulating a research question • Carrying out research
	•

Module number: **MAT**	Module title: **Master Thesis** (18 ECTS / English)
Study program	**Bio-Inspired Engineering**
Position in curriculum	4th semester
Categorization	Master thesis
Level	Advanced students
Previous knowledge	BL1-3, all modules
Block course	n/a
Participating students	Study program students
Contributes to following modules	n/a
Recommended reading	• Books: see respective module relating to topic of Master thesis • Journals: in line with literature research for Master thesis Plus: Best Practice in Scientific Working • Gauch, Hugh G., Jr. (2003), Scientific Method in Practice, Cambridge University Press. • James T. McClave and Terry T Sincich. Statistics. Pearson; 12 edition (2012). • Kate L. Turabian. A Manual for Writers of Research Papers, Theses, and Dissertations, Eighth Edition: Chicago Style for Students and. University Of Chicago Press; 8 edition (March 28, 2013) • Max Planck Gesellschaft. Rules of Good Scientific Practice (2009). Biomimetics as a Science • W. Nachtigall. Bionik als Wissenschaft. Springer-Verlag Berlin Heidelberg (2010) • Y. Helfmna Cohen, Y. Reich. Biomimetic Design Method for Innovation and Sustainability. Springer Verlag (2016).
MOOCs	none

Acquisition of skills	The students • Are able to formulate a relevant research question related to the field of biomimetics • Are able to independently carry out literature research and apply acquired knowledge in a new context • Are able to independently carry out a large part of the biomimetic abstraction process (with the support of their tutor) • Are able to independently carry out most necessary simulations and optimizations • Are able to independently carry out most necessary experiments/feasibility studies • Are able to independently document, (statistically) analyze and interpret the data generated by these studies • Are able to (with the support of their tutor) draw conclusions on the next steps to be taken
Course title	Master Thesis
Number of ECTS	18 ECTS
Position in curriculum	4th semester module/MAT
Teaching & learning methods	Tutoring / coaching
Examination methods	Master thesis and Master examination
Course content	• Identifying an appropriate research topic • Formulating a research question • Literature research • Biomimetic abstraction process • Simulations and optimizations • Planning and carrying out experiments/feasibility studies • Documenting, (statistically) analyzing and interpreting the data generated by these studies • Conclusions and next steps The practical part is complemented by projects from the Biomimetics Lab BL 4: • Option 1: How to make (almost) anything (together with MIT FabAcademy and the CRI-Fablab) • Option 2: How to grow (almost) anything (together with MIT FabAcademy / Harvard Medical School / CRI-Fablab / additional Fablabs) • UE Option 3: Field Trip "The Rainforest of the Austrians" (Costa Rica)