Elective course catalogue for the Master´s Programme Molecular and Cellular Biology

The Elective Course Catalog lists individual courses offered in the Master of Science Molecular and Cellular Biology, including course instructors, descriptions of course contents and qualification goals. Courses are grouped according to subject, according to lectures, seminars and practical courses (in that order). Practical research courses (lab rotations) are listed exemplarily since they vary according to current topics in faculty research groups.

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Lectures, Seminars, Practical courses

Winter term

Main Topic Genetics

Title	Lecture: Genomes and Gene regulation
Content	Within the course the students will learn the following contents: - genomes (ploidy, content, organization, structure) - accessory genomes, extrachromosomal elements, sex chromosomes - Cell cycle regulation - Mitosis and meiosis - transcription and transcriptional regulation (promotors, regulatory elements, transcriptionfactors and regulatory RNAs, processing of RNAs) - epigenetics - translation and regulation of translation - small RNAs
Learning outcomes	The students are capable of - knowledge of the basic genetic and molecular principles of the content above - understanding of the regulatory mechanisms underlaying these principles - - transferknowledge to related biological systems
Responsible contact	Martin, Parniske

Title	Lecture: Recent discoveries in host-microbe interactions
Content	Within the course the students will learn the following contents: - Genetics and evolution of host microbe interactions - The plant-microbe interface - Types of symbiosis between different organisms (mutualism, commensalism, parasitism, …) - Molecular mechanisms of root nodule symbiosis - Molecular mechanisms of arbuscular mycorrhiza - Signaling in tryopanosoma - Allelopathy and chemical molecule crosstalk of plants with other organisms

	- Bacterial entry during root nodule symbiosis and microbial interactions - RNAs in host microbe interactions - Plant disease and plant immunity
Learning outcomes	The students are capable of - a basic understanding of current concepts and insights in host-microbe interactions - a basic understanding of the molecular methods employed to study host/microbe interactions
Responsible contact	Martin, Parniske

Title	Seminar: Food and genes
Content	Life is specified by genomes. Every organism, including the crops that produce our daily foods, has a genome that contains all the biological information—the DNA—needed to build and maintain a living example of that organism. The biological information contained in the DNA is divided into genes, discrete units of the genome. The complete set of genes represents the genetic constitution that makes up the genotype of an organism. Crops often have complex genomes to achieve desired agronomic traits. Yet, crop genomes often exhibit specified genetic diversity to maintain desired agronomic traits. This makes crops vulnerable to infection by co-evolving pests and pathogens and poses ongoing challenges in modern crop breeding to keep up with demands from an increasing world population.
Learning outcomes	This aim of this seminar is to develop an understanding of the unique genetic makeup of our foods and co-evolving pests and pathogens. Evaluating the origin of modern cops and the way they have been bred over centuries to perform best for productivity, human-desired traits, and resistance to environmental stress will be used to gain knowledge on genome architecture and genes regulating agronomic traits. This will be complemented by looking at the genetic diversity present in crops, and evaluating the genomes of co-evolving pests and pathogens to recognise the challenges in food security. A basis for this seminar are the lectures "Genomes" and "Forward and Reverse Genetics".
Responsible contact	Silke, Robatzek

Title	Seminar: Genetics and Society The human genome and its implications for mankind (seminar longitudinal to the lecture genomes and genomics)
Content	Within the course the students will learn the following contents: - the human genome project - CRISPR/Cas - fingerprinting - personalized medizine - pre-implantation diagnostics - ExAc project - Epigenetics - 24 and me
Learning outcomes	The students are capable of - presentation skills - literature search and evaluation - design of scientific questions - literature-based argumentation - moderation of discussions
Responsible contact	Michael, Boshart; Martin, Parniske; Dagmar, Hann

Title	Seminar: Genetic model organisms
Content	In this seminar the most important eukaryotic model organisms for genetic research are presented with a special focus on their respective features, advantages, and limitations. Every seminar day deals with a different model organism, which is introduced by a recent publication that is a good example for the specific topics investigated in this system. Thereby a good overview on different areas of genetic research and especially relevant methods used in molecular genetics is provided. Each student prepares an oral presentation on one model organism using recommended literature and resources, with regular consultation with the instructor. Considerable focus is laid on presentation and discussion. Three separate seminar days cover the topics "How to read a scientific article", "How to make a good presentation", and "Scientific publishing".
Learning outcomes	Students know the most important model organisms for genetic research and their special features. They

	are exposed to current literature, gain insight into language and presentation formats required for peer-reviewed publication, and are able to discuss the scientific topic with their peers. Students are proficient in assessing and preparing a topic employing library and internet resources, can present this topic thoroughly and understandably, and are competent in communication and feedback.
Responsible contact	Andreas, Brachmann

Title	Seminar "Controversial Science evaluation: examples from Molecular Parasitology
Content	Many orginal publications represent the authors interpretation of data that are not always unequivocal and challenged by other researcher´s data. We will use protozoan parasites causing human and veterinary diseases as models focusing on our own research fields. Where possible the students will be asked to discuss two contradicting publications on the same research question.
Learning outcomes	The aim of this seminar series is to improve critical assessment of primary literature and an appreciation how controversial studies and subsequent discussion are crucial to advance knowledge.
Responsible contact	Michael, Boshart

Title	Practical course and Seminar: How to design experiments and write a project proposal
Content	Within the course the students will learn the following contents: - Sustainable development goals of the united nations and their relevance for agriculture - plant root endosymbiosis - Root nodule symbiosis (cell biology, genetics and signaling) - Transcriptional regulation of root nodule symbiosis - genetic diversity in root nodule symbiosis

Learning outcomes	The students are capable of - advanced understanding of literature search and evaluation - advanced understanding of scientific writing skills - knowledge of DFG-style proposals - knowledge of correct citation principles - applied knowledge of methods in plant root nodule symbiosis and experimental planning - detailed project calculation - understanding of the peer-review process
Responsible contact	Martin, Parniske; Macarena, Marin; Dagmar, Hann

Title	Practical course and Seminar: Small RNAs in Plant Microbe Interactions
Content	Small RNAs are non-coding gene regulatory units existing in all kind of life. In this regard, small RNAs are important moderators during the interaction of microbes with their host organisms. In plants, small RNAs regulate immunity by fine-tuning gene expression. However, Pathogens evolved "sneaky" strategies to mimic plant small RNAs in order to transmit them into their hosts to manipulate host immunity for infection. In this course, we will introduce you into the exciting but rather unexplored field of small RNA trans-kingdom communication and to the ways pathogens use small RNAs to invade their hosts.
Learning outcomes	In this course students will study two plant pathogen models, the gray mold pathogen Botrytis cinerea and the downy mildew pathogen Hyaloperonospora arabidopsidis, which use small RNAs for host colonization, by means of modern, state-of-the-art techniques involved in small RNA research and in molecular plant pathology. Students will receive hands-on training in the following techniques: - Fungal culturing and plant infection assays - Pathogen quantification assays - How to deal with (tall) RNAs and small RNAs - Pathogen and plant microRNA and siRNA detection and analysis - Quantification of gene expression (real-time PCR)
Responsible contact	Martin, Parniske; Arne, Weiberg

Main Topic Human Biology - Epigenetics

Title	Lecture course: Methods in epigenetics, cell biology and human biology
Content	Within the course the students will learn the following contents: - Complexity of regulatory Mechanism - Microscopy - Image Analysis - Gene Expression - Proteomics - Alternative Splicing and other regulatory mechanism - Recombinant Antobiodies and their use in molecular biology - Methods to detect DNA modifications - Genomic Engineering - High-Throughput Sequencing Techniques - Model Organism
Learning outcomes	The students are capable of - -knowledge of the basic molecular principles of the content above - -understanding of the regulatory mechanisms underlaying these principles - -transfer knowledge to related biological systems - troubleshooting of experimental approaches
Responsible contact	Daniela, Meilinger; Heinrich, Leonhardt

Title	Seminar: 12 Drugs That Changed The World
Content	Participants in the seminar "12 drugs that changed the world" obtain detailed knowledge on classic drugs that are widely used in medicine as well as recent developed promising drugs. Each student will have to present one topic and students are trained in the presentation of scientific topics. Content: - Aspirin - Penicillin - HIV drugs - Insulin - smallpox vaccine-

	- Morphine - Trastuzumab
Learning outcomes	Skills: - understanding of the molecular principles in respect to the content - relevant literature search - presentation skills - scientific discussion and exchange - feedback
Responsible contact	Daniela, Meilinger

Title	Seminar: 10- toxins that change the world
Content	Participants in the seminar "10- toxins that changed the world" obtain detailed knowledge on famous toxins, their mechanism of action, pharmacokinetics and their medical use. Each student will have to present one topic and students are trained in the presentation of scientific topics. Content: - Hemlock - Aconitum - Belladonna / Atropin - Strychnine - Cyanide - Arsenic - Thalium - Polonium - Mercury - Ricin - Gelsemine - VX agent / Novichok - Botulinum toxin - Brodifacoum - Warfarin - Cholera toxin
Learning outcomes	Skills: - understanding of the molecular principles in respect to the content - relevant literature search - presentation skills - scientific discussion and exchange - feedback
Responsible contact	Daniela, Meilinger; Heinrich, Leonhardt

Title	Seminar: Antibodies and drug conjugates
Content	Participants in the seminar "Antibody-Dug Conjugates (ADCs)" obtain detailed knowledge on ADCs, a class of biopharmaceuticals for targeted chemotherapy. Each student will have to present one topic and students are trained in the presentation of scientific topics. Content: - Approved ADCs - Current challenges in the field - Novel linker chemistries - Novel ADC targets - Novel ADC payloads - Future directions of the field
Learning outcomes	Skills: - understanding of the molecular principles in respect to the content - relevant literature search - presentation skills - scientific discussion and exchange - feedback
Responsible contact	Daniela, Meilinger; Heinrich, Leonhardt; Jonas, Helma-Smets

Title	Seminar: Advances in diagnosis and treatment of human hereditary diseases
Content	We will be discussing 14 selected human hereditary diseases ranging from Sickle Cell Anemia to Chorea Huntington: - Genetic basis - Mode of action - Current treatment - Advances in the last ten years - Perspectives for the future based on recent achievements in science
Learning outcomes	Skills: - Employing Endnote and Citavi for later use - Database searches and accessing original papers - Learn to prepare a topic for a defined audience and a given time frame

	- Give a talk for an audience with experts and layman - Scientific discussion and exchange - Learn to give and receive feedback - Think beyond the framework of current knowledge - Develop visions for future avenues in diagnosis and treatment
Responsible contact	Heinrich, Leonhardt; Heinrich, Flaswinkel

Title	Seminar: Advanced topics in neurodegeneration – exploring next steps in research
Content	This seminar has 2 parts. First, paper dealing with current topics in neurodenerative research will be discussed as part of a literature seminar (each student will be assigned 1 paper). Subsequently, each student is supposed to write a short research proposal exploring their own research ideas based on a paper presented.
Learning outcomes	This is a good practice for writing applications for fellowships and developing own ideas for Master/PhD projects as well scientific writing in general. An introduction as well as supervision for writing research proposals will be provided.
Responsible contact	Heinrich, Leonhardt; Saskia, Hutten

Title	Seminar: Applications of Machine Learning in Biology
Content	Artificial Intelligence, especially in the form of Machine Learning (ML), has become commonplace in recent years. ML is the key technology behind self-driving cars, Go-playing computers and smart assistants like Siri or Alexa, among others. The same technologies are successfully employed across the sciences, including biology, both to automate complex tasks and to derive novel insights from data. In this seminar, we will discuss papers reviewing basic Machine Learning concepts as well as studies applying these techniques

	to diverse biological questions, such as the analysis of (microscope) images and omics data.
Learning outcomes	Skills: - understanding of the basic principles of machine learning - understanding of basics of state-of-the-art deep learning techniques - presentation of methodological details - pros and cons of different techniques - giving constructive feedback - scientific discussion and exchange
Responsible contact	Daniela, Meilinger; Heinrich, Leonhardt; David, Hörl

Title	Practical course and Seminar: Introduction into molecular oncology and epigenetics
Content	Participants in "Introduction into molecular oncology and epigenetics" obtain detailed knowledge of classic and recent methods in the field of epigenetics and molecular oncology, with a focus on apoptosis. - RNA and DNA extraction methods - RT-PCR - Semi-quantitative Western Blot - Quantitative Real Time PCR - Analysis of expression levels of mRNA and proteins - Cell culture handling of different cancer cell lines - Immunostaining - Fluorescencemicroscopy - Data analysis and presentation A mandatory part of this course is an accompanying seminar, which entails the presentation of topics related to oncology, apoptosis and epigenetics to support the practical course. Each student will have to present one topic. Emphasis is placed on hands-on practice with the techniques mentioned above.
Learning outcomes	Students can apply theoretical and practical knowledge to approach biological questions in independent work. Students obtain skills for future lab work in the field of epigenetics and molecular oncology in preparation for future lab work and master's thesis. Skills: - molecular and cellular biology techniques: safe handling with the help of established protocols

	- writing of scientific reports based on journal guidelines - practice critical evaluation and interpretation of data as a basis for careful and relevant conclusions - generating figures using image software - scientific presentation - written data presentation - documentation, interpretation and discussion of the results - social skills (teamwork, mutual respect) - cooperation - fair play - work delegation - communication skills: rapport with instructors and fellow students, presentations, written lab reports - organizational skills: efficient planning, documentation
Responsible contact	Daniela, Meilinger; Heinrich, Leonhardt

Title	Practical course and Seminar: Embryonic stem cells
Content	Participants in "Embryonic stem cells" obtain detailed knowledge of culturing embryonic stem cells and recent methods in the field of epigenetics. During the scope of the practical course participants are introduced to culturing embryonic stem cells and differentiation techniques such as the embryoid body formation. Moreover, they are introduced to "rescue assays" with knock-out cell lines. In addition, students will follow dynamic protein expression changes during differentiation using EpiBlast Differentiation techniques and perform a FRAP analysis. Lab Work: - Cell culture handling of embryonic stem cells - Differentiation techniques, EpiBlast - Rescue experiment of various knock-out cell lines - FACS Sorting - DNA extraction methods - Bisulfite Treatment - Methylation Analysis using deep sequencing - FRAP, performing and data analysis - Immunostaining - Fluorescencemicroscopy - Data analysis and presentation - Emphasis is placed on hands-on practice with the techniques mentioned above.

Learning outcomes	Students can apply theoretical and practical knowledge to approach biological questions in independent work. Students obtain skills for future lab work in the field of epigenetics in preparation for future lab work and master's thesis. Skills: - molecular and cellular biology techniques: safe handling with the help of established protocols - writing of scientific reports based on journal guidelines - practice critical evaluation and interpretation of data as a basis for careful and relevant conclusions - generating figures using image software - scientific presentation - written data presentation - documentation, interpretation and discussion of the results - social skills (teamwork, mutual respect) - cooperation - fair play - communication skills: rapport with instructors and fellow students, presentations, written lab reports - organizational skills: efficient planning, documentation
Responsible contact	Daniela, Meilinger; Heinrich, Leonhardt

Main Topic Human Biology – Human Genomics

Title	Lecture: Computational Methods in Population Genetics I
Content	Contents are Maximum-Likelihood methods and Bayesian approaches for the estimation of population genetic parameters (e.g. population structure, growth and migration rates). In the lecture, the underlying models (e.g. coalescent and ancestral recombination graph), statistical principles, and computational strategies (e.g. importance sampling and MCMC) are discussed. During the exercises, students will analyse the methods learned in the corresponding lectures. They will also try out various software packages (e.g. Hudson's MS, LAMARC, GENETREE, IMa2) and explore by computer simulation studies under which circumstances they are appropriate. Further exercises

	will help the students to improve their comprehension of the lecture's content.
Learning outcomes	The students will have the theoretical background in order to interpret and critically judge the results of population genetic analyses. In addition, students are able to infer evolutionary and ecological features, using various software packages, methods and models.
Responsible contact	Dirk, Metzler; Ricardo, Pereira

Title	Lecture Phylogenetics I
Content	Maximum-Likelihood-based methods for inferrence of phylogeny from genetic data; comparison to parsimonious and distance based approaches; theoretical and mathematical backgrounds such as stochastic models of sequence evoltion; Application of software packages such as PHYLIP and RAxML
Learning outcomes	Understand principles and rationales underlying the most important methods of phylogeny inferrence, be able to perform basic phylogenetic analyses with available software packages, understand which fundamental problems in phylogenetics are efficiently solvable and which are computationally intractable, understand the strengths and weaknesses of different approaches and be able to judge which method is appropriate for which dataset, understand theoretical background (including most important bioinformatic algorithms in phylogentics) and mathematical notations that are necessary to read software documentantion and publications on phylogenetic analyses
Responsible contact	Dirk, Metzler; Sebastian, Höhna

Title	Lecture Phylogenetics II

Content	Contents are computational methods for the reconstruction of phylogenetic trees as well as the underlying probabilistic evolution models and statistical principles, in particular Maximum-Likelihood and Bayesian Methods, including statistical-bioinformatic methods for special areas of phylogenetics as for example relaxed molecular clocks for fossil-based time calibration, evolution of quantitative traits, reconciliation of gene trees and species trees, or phylogenetic alignment. The theoretical models and algorithms underlying the methods are also treated. The theoretical backgrounds of Markov-Chain Monte-Carlo (MCMC) methods are discussed, as well as aspects of their application. The participants will use the knowledge gained in the lecture and apply this to actual data sets. They will learn to use phylogentic software, including RAxML and BEAST. They perform simulation studies for various scenarios to assess whether and, if so, how the methods can be applied. The students will solve theoretical exercises to improve their comprehension of the lecture's contents.
Learning outcomes	As a basis for their scientific specialisation, students achieve an in-depth comprehension of advanced phylogenetic methods. They will have the fundamental knowledge to acquire related methods from the literature. The students learn to perform data analyses with the methods taught in the lecture and to interpretate and critically judge the results of such analyses.
Responsible contact	Dirk, Metzler; Sebastian, Höhna

Title	Lecture: Human genomics
Content	This lecture builds on knowledge obtained in molecular biology and genetics on the Bachelor's level. It aims to deepen an understanding how the human genome was sequenced and annotated and how it is currently used to study human biology in health and disease. The following topics are addressed: The human genome project, high throughput sequencing technologies, basics in sequence analysis, gene annotation, gene expression analysis.
Learning outcomes	The students will be able to describe and understand fundamental principles of human genomic research.

	They will acquire the basic background knowledge to apply genomic technologies.
Responsible contact	Wolfgang, Enard; Ines, Hellmann

Title	Lecture: Computational Methods in Population Genetics II
Content	In depth we treat state-of-the art data analysis methods for special problems in population genetics as for example novel variants of Approximate Bayesian Computation (ABC), Approximations of the Ancestral Recombination Graph, the Ancestral Selection Graph and/or novel methods for analyzing genome-wide sequence data. Contents are also the theoretical models and algorithms underlying these methods. In the tutorial the students learn to use software to analyze data with the methods learned in the corresponding lecture. They test these methods with empirical and simulated data. Theoretical exercises will help the students to improve their understanding of the lecture's contents.
Learning outcomes	As basis for their scientific specialization, students achieve an in-depth understanding of special computational methods for analyzing population genetic data. This knowledge will enable them to acquire the comprehension of related methods from the current literature. In addition, the students will learn to perform data analyses with the methods learned in the lecture and to critically interpret the results of such analyses.
Responsible contact	Dirk, Metzler; Ricardo, Pereira

Title	Seminar: DNA-Repair
Content	In this 2-day seminar, students critically discuss recent publications in the field of DNA repair and damage response. 2-3 topics will each be addressed by several

	publications so that students learn to draw conclusions from heterogeneous and sometimes controversial publications. From a list provided by the supervisors, students select a publication which they will present in the seminar. They search for additional relevant literature to provide a short introduction into the topic. This will, together with information obtained in discussion of individual papers, provide a deeper knowledge into basic principle of repair and damage response, and their links to cancerogenesis and radiation protection. Students will present open questions and the aim of the work described in the chosen publication, the main methods used and the results obtained in a powerpoint presentations. Specifically students are asked to critically evaluate strengths and weaknesses of the publications.
Learning outcomes	Students are proficient in presentation skills with different media, are introduced to library and internet resources, can assess and present a topic thoroughly and understandably to scientific peers. They will be able to critically assess scientific publications.
Responsible contact	Simone, Mörtl; Anna, Friedl

Title	Seminar: Animal Models for Psychiatric Disorders
Content	In the seminar, the students critically discuss the use and applications for animal models for psychiatric disorders, with a special focus on major depression and anxiety-related disorders. The students learn which approaches for translational psychiatry are state-of-the-art, which model systems are used and which molecular and behavioral readouts are applied to study psychiatric disorders.
Learning outcomes	Using examples from the recent literature, the students learn how to read and judge a scientific paper and how to summarize the key findings in a scientific presentation. The implications of different scientific approaches using animal models are discussed. Furthermore, the students learn to collect the diverse information on a specific topic related to the overall theme of the seminar and to compose a written assay about this.
Responsible contact	Carsten, Wotjak; Mathias, Schmidt

Title	Seminar: 3D genome organisation and cell fate - methods and functional importance
Content	How different phenotypes emerge from genetically identical cells is one of the major topics in biology. Dynamic regulation of the epigenome underlies cellular plasticity and epigenetic deregulation has been associated with a variety of diseases including developmental disorders and cancer. In addition to chromatin modifications and non-coding RNAs, three-dimensional genome organization has emerged recently as intimately linked to transcription and cell fate and is an exciting new aspect of epigenetic regulation. Changes in nuclear architecture and spatial positioning of gene loci can affect transcriptional output and ultimately cell fate, and disruptions in topology can result in pathogenic phenotypes. Furthermore, genomic rearrangements frequently occur in cancer cells and these are at least in part guided by the three-dimensional organization of the nucleus. In this seminar we will cover the major experimental and computational methods to analyse 3D genome architecture. We will discuss how such topology can influence gene regulation, guide regulatory interactions and ultimately cell fate. We will also debate some of the current hot topics in the field such as topologically associated domains, loop extrusion and the molecular mechanisms for establishing and maintaining the different layers of 3D nuclear architecture.
Learning outcomes	The students will get an overview on the field of 3D genome organisation and will be able to understand, present, discuss and critically judge current literature in the field.
Responsible contact	Wolfgang, Enard; Boyan, Bonev

Title	Practical course: DNA-Repair
Content	In the context of a general overview on cellular response mechanisms to DNA damage, students will set up and perform experiments linked to current

	research topics in the field of DNA repair of the supervisors at LMU and Helmholtz Zentrum München. Both basic molecular and cellular methods (such as mammalian tissue culture, immunofluorescence and microscopy, or Western Blot) and more specialized methods (such as high throughput analyses) are used. Emphasis is placed on hands-on practice in small groups (max. 8 participants), planning of experiments with appropriate controls, and interpretation of data. Students will evaluate their data and critically discuss their results in short oral presentations on the last day.
Learning outcomes	Students will be able to set up experiments following a written protocol, to quantitatively evaluate and present the obtained data and to reflect on the validity and limitations of the information derived from the experiments, in preparation to the requirements of the master's thesis. They will be proficient in basic knowledge on DNA damage response mechanisms and in applying theoretical and practical knowledge to approach biological questions in independent work. They will be able to communicate their research results and to participate in a scientific discussion.
Responsible contact	Simone, Mörtl; Anna, Friedl; Kristian, Unger

Title	Seminar and Practical course: Computational analysis of RNA-Seq data
Content	Whole transcriptome analysis by RNA-seq is on the verge of becoming a standard analysis in many molecular biology laboratories. As it is the case for many next generation sequencing (NGS) based methods, the analysis of the data is often more complex than the generation of the data and biologists often (wrongly) believe that the analysis falls in the domain of bioinformaticians. This course aims to set this record straight by enabling students to analyse RNA-seq data by executing and most importantly understanding the following steps: 1. Basic handling skills of NGS data accessing a unix server via the shell commandline. 2. Normalisation and outlier removal of RNA-seq data. 3. Differential expression analysis. 4. Gene-set enrichment analysis. 5. Gene expression network analysis.
Learning outcomes	This course enables students to analyse RNA-seq data starting from raw sequence files ending with expression network analysis.

Responsible contact	Wolfgang, Enard; Ines, Hellmann; Beate, Vieth

Title	Practical course Single Cell Analysis Techniques in Epigenetics Research
Content	This course focuses on single cell biology. Specifically, we will address how to apply three different, but highly complementary approaches: Quantitative light microscopy, microfluidics and RNA-seq to study gene expression. The first part of the course will focus on the physical principles, technical developments and computational tools that form the basis of modern microscopy techniques and their application in live and confocal microscopy. In addition, the basics behind microfluidic device development and fabrication, as well as its application for addressing single cell questions will be taught. This will enable students to design, master, and analyse microscopy experiments to study reporter and protein expression in single cells. The second part will cover the basics of single cell RNA-seq, from the design of experiments to the state-of-the-art computational tools for data analysis. The students will learn how to implement gene expression analysis pipelines to study single cells.
Learning outcomes	At the end of the course the students will be able to: - Utilise basic and advanced microscopy approaches for quantitative live cell imaging. - Design and troubleshoot cell tracking experiments. - Apply image analysis pipelines for cell tracking, segmentation and quantification. - Design and use microfluidics devices for single cell tracking for microscopy and/or NGS. - Apply design principles for single cell RNA-seq experiments. - Analyse single cell RNA-seq datasets to quantify gene expression and analyse cell populations. - Utilise single cell RNA-seq datasets to establish cell fate maps
Responsible contact	Robert, Schneider

Title	Practical on Computational Methods in Population Genetics
Content	This practical class starts with a lecture, followed by with exercises in which each student will explore a different data set and present the results daily. The course is structured under two major methodologies that are commonly used in current literature on Population Genetics: 1. Determine populations structure, 2. Determine gene flow during divergence. Through these methodologies, the students will learn several concepts of population genetics such as: Hardy-Weinberg equilibrium, Linkage disequilibrium, vicariance, hybridization, coalescent, and introgression.
Learning outcomes	In this master-level course, the students will: - Get familiar with working in a computer cluster; - Get familiar with UNIX computational language; - Get familiar with the Bayesian clustering method implemented in the programme STRUCTURE (Pritchard et al. 2---); - Get familiar with the coalescent analysis implemented in the programme IMa2 (Hey and Nielsen 2--4); - Learn how to analyze and present results from these methodologies
Responsible contact	Jochen, Wolf

Main Topic Microbiology

Title	Lecture: An Introduction to Electron Microscopy
Content	The major components and working principles of an electron microscope will be demonstrated. Furthermore, the function and resolution of scanning and transmission electron microscopes as well as selected preparation and analytical methods will be explained in more detail.
Learning outcomes	The lecture should enable the students to understand the basic principles of electron microscopy and electron optics. This includes a deeper insight into the

	respective literature and publications. This lecture provides sufficient knowledge to successfully carry out internships and practical courses in the field of electron microscopy. Furthermore, students passing this lecture will be able to evaluate electron micrographs and the potential application of the presented methods in their own projects.
Responsible contact	Andreas, Klingl

Title	Lecture: Molecular virology (part I: basic virology)
Content	"Molecular Virology I" covers basic principles of virology with respect to virus taxonomy, replication and expression strategies, methodologies and focuses on specific virus families, particularly RNA viruses. Credits require the passing of a final exam.
Learning outcomes	In conjunction with course 2, the students gain an overview of the major RNA virus families, their molecular features, replication strategies of viruses, major discoveries in cell biology made by the study of viruses, principles of molecular virology, and strategies for the development of antiviral inhibitors, among others. This lecture series puts students in the position to appreciate the significance of virology on biology and provides important knowledge for independent research work in various areas, including molecular virology, human biology and cell biology.
Responsible contact	Ruth, Brack-Werner; Hans-Michael, Nitschko; Bettina, Kempkes

Title	Lecture: Prokaryote-eukaryote interactions
Content	The lecture presents basic principles of microbial ecology of organismic interactions and covers bacterial as well as fungal interactions with plants and animals/humans. Also bacterial-fungal interactions are covered. The quality of interactions deals with the whole spectrum from pathogenic, saprophytic to

	symbiotic interactions. Besides the presentations of examples of organismic interactions, basic mechanisms are taught including molecular signaling, specific gene expression and ecological niche occupation. Students get an insight into trans-kingdom interactions of organisms including common principles and basic mechanisms like quorum sensing signal production at the bacterial and QS-perception at the eukaryotic side. Also different types of mycorrhizal symbiosis as well as different symbiotic nitrogen fixation systems are presented.
Learning outcomes	Students acquire detailed and over-arching understanding about the contents of the course and are able to depict basic principles and transfer knowledge in an exam situation. Students have fundamental as well as up-to-date knowledge. The latter is published as original articles and not yet found in text books. Creative thinking and dialog between the students are encouraged.
Responsible contact	Frank, Landgraf; Pascal, Falter-Braun

Title	Lecture: Microbial Physiology and Synthetic Biology
Content	The lecture builds on the Bachelor's level, the module aims to significantly deepen and expand knowledge and understanding in the areas of Microbial Physiology and Synthetic Biology. The following topics are addressed: Microbial cell structure and function, Signal transduction and regulation in microorganisms, Membrane bioenergetics and solute transport; Metabolism of bacteria under aerobic and anaerobic conditions;Degradation of polymers by microorganisms; Metabolism of inorganic compounds and iron acquisition; Synthetic biology: history and basic concepts; Foundation technologies / minimal cells and genomes; Parts, devices and systems.
Learning outcomes	The students will be able to integrate knowledge and deal with the complexity of Microbial Physiology and to apply these capabilities to new approaches in Synthetic Biology. They learn to make scientifically sound decisions in the areas of Microbial Physiology and Synthetic Biology considering scientific and ethical evidence.

Responsible contact	Heinrich, Jung; Jürgen, Lassak

Title	Lecture: Detection and analysis of biomolecules - Microscopy and spectroscopy in the life sciences
Content	The lecture builds on the Bachelor's level knowledge in the areas of biochemistry and biophysics. The lecture aims to significantly deepen and expand knowledge and understanding in the areas of light-matter interactions applied to biological systems. The following topics are addressed: Basic optical principles; Optical properties of biomolecules; Fluorescence spectroscopy; Chirooptical and scattering methods; Magnetic resonance techniques; Mass spectrometry; Light microscopy; Resolution and contrast in optical microscopy; Fluorescence microscopy; Dynamic fluorescence imaging; Super-resolution microscopy; Single-molecule techniques; Ultrafast spectroscopy; DNA sequencing & Special techniques
Learning outcomes	Upon completion of this course, the student is able to comprehend the working principle of modern optical microscopy and spectroscopy techniques. The student can review and judge the quality of specialized literature about lecture topics and apply this knowledge to research projects. This includes assessment procedures on how to choose a suited technique for a certain type of research/question.
Responsible contact	Thorben, Cordes

Title	Seminar: Microbial Physiology and Synthetic Biology
Content	In the seminar, the students critically discuss problems related to the topics of the lecture: Microbial cell structure and function, Signal transduction and regulation in microorganisms, Membrane bioenergetics and solute transport; Metabolism of

	bacteria under aerobic and anaerobic conditions; Degradation of polymers by microorganisms; Metabolism of inorganic compounds and iron acquisition; Synthetic biology: history and basic concepts; Foundation technologies / minimal cells and genomes; Parts, devices and systems. The students develop and apply own ideas. Specifically, the students select a topic, search and read relevant publications, develop based on the current state of knowledge aims and experimental strategy for an own research project that they present and discuss in the seminar.
Learning outcomes	The students will be able to communicate their conclusions in a clear and unambiguous manner and to exchange information and ideas on a scientific level with experts in Microbial Physiology and Synthetic Biology and with laypersons.
Responsible contact	Heinrich, Jung; Sophie, Brameyer

Title	Seminar - Hot topics in (cryo) electron microscopy
Content	The seminar covers the most recent and advanced developments and inventions in high-resolution (cryo) electron microscopy and closely related areas. It deals with the variety of advanced (cryo) methods applied in electron microscopy in general an which are partially also applied at our institute. These are methods like high-pressure freezing, imunogold localization, 3D structure of cells, SBF-SEM, FIB/SEM-tomography, TEM- and STEM-tomography or single particle analysis. In the seminar, students are working on a selected topic which includes the discussion on a current publication applying the respective method.
Learning outcomes	Within this seminar, students can intensify and deepen the knowledge gained in the lecture 'An introduction to electron microscopy'. They will get insight into the application of advanced methods, experience limitations and shortcomings of the techniques. After the seminar, students will be able to understand the technical principles and to discuss about the presented methods with other researchers in that scientific field.
Responsible contact	Andreas, Klingl; Carolin, Pickl

Title	Seminar and Excursion: Microbiology
Content	Students are introduced to various practical and applied aspects of microbiology. This will include scientifically guided field trips to various biotech companies from the start-up to large enterprise level, extra-university research institutions, sewage treatment plants, and others. Participants will become familiar with several aspects of applied biotechnological research, the microbial production of food, pharmaceuticals and diagnostics, as well as microbial waste-water treatment technology. Students gain insights into the organizational structures and strategies of real-world, non-academic companies and research institutions and will get into contact with prospective employers.
Learning outcomes	Students become familiar with cutting-edge non-academic research and production using applied microbiology. Students are able to extent and transfer their theoretical knowledge into real-world applications of various fields of microbiology.
Responsible contact	Kirsten, Jung

Title	Seminar: Novel techniques and approaches in physical biology
Content	The seminar builds on the Bachelor's level knowledge in the areas of biochemistry and biophysics. The seminar aims to significantly deepen and expand knowledge and understanding in the areas of light-matter interactions (microscopy and spectroscopy), which are applied to biological systems. The participants will hear research-related lectures of projects in the AG Cordes and prepare lectures themselves based on recent research articles published in the area of physical biology. These include both method development and mechanistic studies.
Learning outcomes	Upon completion of this course, the student is able to understand how physical techniques are applied for mechanistic studies in biology. The student can review and judge the quality of specialized literature about the

	seminar topics and apply this knowledge to research projects.
Responsible contact	Thorben, Cordes

Title	Practical course: Bacterial Proteomics
Content	Bacteria may alter cell morphology, cell metabolism and gene transcription in response to environmental fluctuations, such as availability of carbon sources, oxygen, and nitrogen. Within the frame of the course students will grow Escherichia coli, one of the best investigated model organisms, under various, well defined conditions in fermenters. Subsequently, the proteome of each culture, representing the entire set of proteins expressed by a genome, will be analysed and assigned to the external conditions.
Learning outcomes	Students will learn to use fermenters, in order to learn how to cultivate bacteria under defined conditions. The working principle of our course fermenters is, basically, the same as those used in industry. Furthermore, proteome analysis methods provide valuable insights for the investigated organisms and are used in many research laboratories.
Responsible contact	Kirsten, Jung; Frank, Landgraf

Title	Practical course and seminar: Prokaryote-eukaryote interactions
Content	The seminar covers up-to-date topics on trans-kingdom interactions of prokaryotes with eukaryotic hosts. The topics include symbiotic as well as pathogenic interactions and also deal with bacterial-fungal interactions. Biochemical mechanisms of interactions, like specific recognition and receptor interactions, small molecule signaling and signal transfer. Each

	student selects a specific topic and is requested to present a review article and original research literature, which he/she has selected within the topic. Based on this literature, each student has to prepare a presentation which contains a general introduction and overview part as well as an experimental results part followed by a discussion and summary. A discussion involving all seminar participants is obligatory.
Learning outcomes	Students are familiar with in the contents of the course and are able to depict basic principles and transfer knowledge in widened connections. Students have fundamental as well as up-to-date knowledge. Specifically, the students are equipped with knowledge on evaluation, presentation and critical discussion of state-of-the-art problems in molecular microbial ecology and organismic interactions. Students are equipped with adequate presentations skills, including the use of a scientific library and internet resources. Students have improved skills to speak in front of a group, improve and train their (English) language and communication abilities. Seminar discussions foster creative thinking and the dialog with and interactions between the students.
Responsible contact	Frank, Landgraf; Pascal, Falter-Braun

Main Topic Cell Biology

Title	Lecture: Biochemistry and cell biology of plants
Content	The lecture builds on the Bachelor's level and covers advanced aspects of plant cell biology and biochemistry. The following topics are addressed: (1) Plant energy metabolism: Evolution, ecology and biochemistry of photosynthesis; Photorespiration; Plant mitochondrial respiration; Endosymbiosis and evolution of plant organelles. (2) Plant carbohydrate metabolism: Metabolic pathways and their regulation; Cell wall structure and function. (3) Plant signaling: phytohormones as signals within and between plants, light receptors (structure and

	molecular mechanisms of light sensing and signaling), metabolic signals. (4) Plant transport: Protein transport and intercellular communication; phloem structure and long-distance transport, stomata and water transport/gas exchange.
Learning outcomes	The students will be able to integrate knowledge and deal with the complexity of plant biology from a cellular to a whole plant level. They obtain fundamental knowledge about plant cell structure and function. They are able to interpret the outcome of plant biochemical regulation and cellular organisation on the level of plant tissue and organs. They obtain insights into how plants sense, transduce and respond to environmental signals, and how nutrients and signals are transported within and between plants cells and organs.
Responsible contact	Peter, Geigenberger; Thomas, Nägele

Title	Lecture: Mechanism of Animal Development: Invertebrate Models
Content	This course covers fundamental mechanisms of animal development, as determined using the model invertebrates, Drosophila melanogaster and Caenorhabditis elegans. Basic principles are discussed, as are the experimental methodologies that have led to key discoveries.
Learning outcomes	The students are proficient in the basic developmental biology (embryology and fate maps) of Drosophila and C. elegans. Students are familiar with the genetic, molecular, and experimental methods used to elucidate principles of development. Students are able to interpret novel data sets, formulate hypotheses, and suggest experimental approaches that could be used to test these hypotheses. Students are able to integrate knowledge from lecture with information obtained through online data searches
Responsible contact	Nicolas, Gompel

Title	Lecture: From cannabis and nicotine to anti-cancer drugs - plant derived drugs and how they function in plants and in humans
Content	The powerful and often well-known plant-derived drugs interact with molecular and cellular mechanisms in animals, including humans. As an interdisciplinary approach between plant and animal cell biology, it covers, on the one hand, cellular signal transduction mechanisms in animals, concentrating on seven-transmembrane receptors (GPCRs) and ion channels, but also on cancer cell growth. On the other hand, it describes how and why plants produce these secondary metabolites. The interplay between these topics is illustrated by elaboration on prominent plant-derived drugs that constitute potent plant toxins, pharmaceutically used drugs to treat human disease as well as so-called recreational drugs.
Learning outcomes	The students wil be able to integrate knowledge in an interdisciplinary way learning also to understand how co-evolution can happen.
Responsible contact	Cordelia, Bolle; Angelika, Böttger

Title	Lecture Transcriptional regulation from DNA to diversity
Content	This lecture describes how embryonic development, particularly in animals, is controlled at the transcriptional level. It is rooted in a historical perspective on research in genetics, embryology and the birth of molecular biology. It reviews the basic molecular mechanisms of Eukaryotic transcription of DNA into RNA, as well as the different levels of regulation of this process. The lecture has a strong emphasis on cis-regulatory elements, and much less emphasis on epigenetic regulation. Finally, the lecture examines the consequences of the molecular processes on cell specification and differentiation, tissue patterning and morphogenesis, as well as species evolution.

Learning outcomes	The students will have an overview on the transcriptional control of embryonic development. In particular the lecture highlights the relationships between different levels of biological complexity, from molecules, to cells, to organs and to the entire organism. In addition, the lecture provides a solid refresher on the basic mechanisms of gene transcriptional regulation.
Responsible contact	Stephane, Rolland; Nicolas, Gompel

Title	Seminar: From genes to behavior
Content	How do genes define the behavior of humans and animals? Based on this question, we will explore examples that link the function of single genes to the behavior of an organism. These behaviors include mating behavior, individual personality and learning. One research paper from primary literature is assigned to each student. Using additional literature and feedback from the instructor, students prepare an oral presentation on their topic and present it in front of an audience.
Learning outcomes	Students will get an overview of various topics from the field, as well as the basis of genetic and behavioral analysis. They will gain insight into methodology and the practical aspects of various different model organisms. Furthermore, they will learn how to present and structure scientific data, as well as how to critically discuss it with their audience.
Responsible contact	Nicolas, Gompel; Lasse, Bräcker

Title	Seminar: Design of experiments in plant science
Content	Research projects related to current questions in plant science are assigned to each participant. The aim is that the students research the topics independently by finding appropriate literature and resource. Then the students' task is to apply learned techniques to this

	topic and to propose how to address these scientific questions. Students consult regularly with the instructor. The seminar requires an oral presentation of the proposed research plan to the entire group. In addition, a written proposal has to be submitted.
Learning outcomes	Students need to apply (theoretically) acquired knowledge about techniques and methods to the scientific questions posed. This allows a transfer of knowledge and application of techniques learned in different lectures and practical courses. Furthermore, the students are introduced to library and internet resources, and can sharpen presentation skills gained through speaking in front of a group. To learn how to plan experiments is fundamental for a further scientific career.
Responsible contact	Cordelia, Bolle; Dario, Leister; Anja, Schneider

Title	Seminar: Molecular and ecological aspects of biotechnology with microalgae and cyanobacteria
Content	In the seminar, the students present and discuss recent literature dealing with biotechnological and ecological aspects of algal cultivation. Topics are: Ecological optimization of algal mass cultivation in bioreactors and open pond systems; The use of micro-algae and cyanobacteria trait diversity to create product-tailored growth systems; Biotechnological optimization of algal mass cultivation in bioreactors; Modern methods of molecular plant sciences to optimize the yield of desired/valuable products in algal growth systems; The use of genetically modified microalgae and cyanobacteria for commercial algal growth systems. Risks and risk-evaluation of genetically modified algae and cyanobacteria for natural aquatic systems. Students will prepare a topic, search and read relevant publications and present a talk.
Learning outcomes	The students will be able to present the content of scientific publications in a clear and focused manner within a given time frame. Students will be able to integrate knowledge from Molecular Plant Sciences and Ecology and to apply it to modern approaches in Biotechnology but also Environmental Sciences. Students will be able to exchange information and arguments about genetically modified organisms on a scientific level with experts and with laypersons.

Responsible contact	Herwig, Stibor; Jörg, Nickelsen

Title	Seminar: From centrioles to microcephaly
Content	Centrioles play an extremely important role for human health. On one side they are part of the centrosome, the main microtubule-organizing center of animal cells. On the other hand, as basal bodies they template primary, sensory and motile cilia. Defects in centrioles and cilia can lead to many human conditions ranging from cancer, to congenital heart diseases and microcephaly. The seminar will explore the selected topics of molecular mechanisms regulating centrioles and cilia biogenesis are linked to these human conditions.
Learning outcomes	Students will acquire in depth knowledge about the state of the art of selected topics in biogenesis of centriole and cilia, their underlying molecular mechanisms and their relevance to human health. By presenting a selected scientific paper students will train their presentation and communication skills. The course has an emphasis on critical reading and analysis of primary scientific literature. While analyzing the primary literature students will explore how scientists pose their questions, which methods they use to answer them and how they come to their conclusions. Students will be encouraged to critically evaluate whether the presented data lead to the conclusions, to think about follow up questions and to actively participate in discussions.
Responsible contact	Tamara, Mikeladze-Dvali

Title	Seminar: The genetic origin of evolving traits
Content	The seminar will cover important recent literature in the field of evolution and development ("evo-devo"). Research papers will be assigned to each participant. Each student will have to independently read, understand a paper and prepare a presentation. The student is invited to use resources and literature beyond the assigned paper. This is a two-days block

	seminar during which each student will present a paper and moderate the discussion around another paper presented by another student.
Learning outcomes	The students will improve their skills to read a paper, dissect its scientific content, present this content to an audience that has not read the paper. The seminar wil also highlight genetic principles underlying morphological evolution in animals and plants.
Responsible contact	Stephane, Rolland; Nicolas, Gompel

Title	Seminar: Molecular mechanisms of cytokinesis in animal cells
Content	The seminar will be 3 hours/week and the students will select a scientific publication from a list. Each student will write a ½ page summary about the publication which will be sent to the other participants. During the seminar each student will present the selected scientific publication in an oral presentation. In the presentation the students should give an introduction into the scientific background, the main question addressed, the key results and the future perspective of the study. In addition controls missing in the publication or misinterpretation of the presented data should be discussed by the students.
Learning outcomes	Students will learn how to critically read and discuss a scientific publication in the field of cytokinesis. They will also improve their scientific oral presentation skills.
Responsible contact	Esther, Zanin; Christof, Osman

Title	Seminar: Stem cells
Content	Topics related to different aspects of stem cell biology are assigned to each student. These include embryonic stem cells, experimental approaches to cell fate manipulation, adult stem cells and their niches and others. Using recommended literature and resources,

	and with regular consultation with the instructor, students independently research the topic.
Learning outcomes	Students are proficient in presentation skills using PowerPoint, are introduced to library and internet resources, can assess and present a topic thoroughly and understandably to a group and critically evaluate the presented literature. They will be exposed to elder literature describing the beginnings of research on embryonic stem cells and literature about recent advances in the field, and acquire knowledge about current events in stem cell research. This enables them to participate in more general discussions of this topic.
Responsible contact	Angelika, Böttger

Title	Seminar: Molecular mechanisms of cell division
Content	This seminar is intended for students actively participating in the research of the laboratories. Each week the students will participate in the seminar /group meeting where recent data is presented and discussed. During the meeting (3 hours/week) a scientific publication will be discussed by all participating students. Additionally the student has to select one publication and give an introduction into the scientific background, the main question addressed, the key results and the future perspective of the study. In addition controls missing in the publication or misinterpretation of the presented data are be discusses by the students
Learning outcomes	Students will learn how to critically read and discuss a scientific publication in the field of cell division. They will also improve their scientific oral presentation skills.
Responsible contact	Christof, Osman

Title	Seminar: Mitochondrial unfolded protein response
Content	Mitochondria are essential organelles that play important roles in various processes, such as energy

	production, cell signaling and apoptosis. Protein quality control in mitochondria is regulated by a signaling pathway called mitochondrial unfolded protein response (UPRmt). During this seminar, we will see how this important signaling pathway has been discovered. This seminar is a 2-days block seminar during which each student will present a publication. Half of the selected publications described the UPRmt response in C. elegans while the other half described this response in mammalian cells. This selection will show the students how conserved this response is in different organisms. Furthermore, publications have been selected in a way that publications presented by some students will be connected to publications presented by other students. This organization helps to foster group discussion. Furthermore, the students will be exposed to "old" as well as more recent publications, which will give the students an idea of the evolution of the experimental approaches and scientific knowledge. Each presentation will be followed by a group discussion.
Learning outcomes	With this course, the students will improve their skills on (i) how to read a publication with a critical eye, (ii) how the basic knowledge they learn in lectures was actually scientifically discovered, (iii) how to present their findings to an audience and finally (iv) how to ask questions.
Responsible contact	Stephane, Rolland; Thorben, Cordes

Title	Practical course: Molecular Plant Biology
Content	The aim of this course is to teach relevant methods within the background of fundamental principles in plant science. We compare Arabidopsis mutants with defects in the photosynthesis on the physiological (state transition measurements) and biochemical level. Participants are introduced to advanced biochemical techniques such as the isolation of protein complexes (photosystems) and to analyze them with Blue Native Gel analysis, 2D gel electrophoresis, and Western analysis. Furthermore expression patterns in the nucleus are explored (Northern blot and RT PCR, non-radioactive labeling of probes). The emphasis lies on hands-on practice as the students are preparing every step of the experiment themselves, from making solutions to discussing the results. Furthermore, they are trained to compare different methods and to

	understand the biological and biochemical background of the methods used.
Learning outcomes	Students obtain necessary skills for future lab work, in particular in preparation for their master's thesis. The methods are taught in reference to the biological questions asked. Therefore, a transfer of theoretical knowledge to practical applications can be made. In working in small lab groups, social skills (teamwork, cooperation, fair play, work delegation, mutual respect), communication skills (rapport with instructors and fellow students, presentations, written lab reports), as well as organizational skills (efficient planning, documentation) are refined.
Responsible contact	Cordelia, Bolle

Title	Practical course: Drosophila genetics and neurogenetics
Content	This course is a hands-on illustration of modern approaches to study the model organism Drosophila melanogaster. The students will be presented with state-of-the-art techniques used to address fundamental questions in developmental biology and neurosciences. The first part of the practical course will concentrate on the formation of gene expression patterns and their relationships to morphological phenotypes. It will focus on Drosophila wing development to illustrate these processes. The second part of the course will explore how the function of nervous system can be studied in a developed organism, and in particular how modern research deciphers the relationship between neuronal circuits and animal behavior. The practical course will cover several techniques including classical fly genetics, the use of transgenic lines, microscopy, micro-dissection, immunochemistry, image analysis.
Learning outcomes	The students will have concrete notions of how research with Drosophila is conducted. In particular, they will see the connections between formal genetics,

	phenotypic analysis, and how this relates to gene expression and function.
Responsible contact	Nicolas, Gompel; Lasse, Bräcker

Title	Seminar and practical course: Mechanisms of cell proliferation and differentiation
Content	Participants are introduced 1. to hydra as a model organism for studying proliferation and differentiation processes in the context of a whole organism. Students get hands-on experience in analysing the cell cycle and differentiation kinetics of different cell types in hydra. They conduct regeneration experiments to reveal fundamental principles of tissue self-organisation and pattern formation and the role of specific molecular signalling pathways in regulating developmental processes. 2. to a cellular model for studying proliferation and differentiation in tissue culture.
Learning outcomes	Students obtain skills for future lab work, in particular in preparation for their Master theses. These include skills in preparing of biological specimens, fluorescent dye and antibody staining and use of standard visualization techniques with phase contrast and fluorescence light microscopy. Students can apply theoretical and practical knowledge to approach biological questions in independent work. They learn to design experiments allowing conclusions about cell and tissue homeostasis and mechanisms of pattern formation in a simple animal and in tissue culture cells. Students are trained in good general lab practice, including standard safety procedures, precise handling of chemicals and optical instruments, conscientious documentation of lab procedures, critical evaluation and interpretation of data as a basis for careful and relevant conclusions. In working in small lab groups social skills (teamwork, cooperation, fair play, work delegation, mutual respect), communication skills (rapport with instructors and fellow students, presentations of theoretical

	background and results, written lab reports), as well as organizational skills (efficient planning, documentation) are refined.
Responsible contact	Angelika, Böttger

Title	Practical course and Seminar: Systems Biology
Content	The seminar introduces theoretical basics of systems biology and builds on Bachelor's level in biochemistry, molecular biology and mathematics. Further, it introduces to computational approaches of metabolic modelling. Addressed topics are (i) metabolic networks, (ii) enzyme kinetics, (iii) biochemical regulation, (iv) kinetic modelling and (v) statistics. The practical course will introduce to experimental analysis in plant systems biology. The students will apply experimental methods of enzyme kinetics, metabolite quantification and flux measurements of CO2 uptake and release via photosynthesis and respiration. The practical course will introduce to buffer systems for enzyme extraction, photometric metabolite quantification and infrared spectroscopy. Experimental parameters will be computationally analysed using software packages for metabolic modelling.
Learning outcomes	Seminar:The students will be able to integrate quantitative data on metabolism, e.g. enzyme kinetics and proteomics data, in context of metabolic regulation. They will be able to communicate and present their conclusions in an unambiguous manner. They will gain expertise in exchanging information on a scientific level with experts in the research field of systems biology. Practical course: The students will be able to quantify diurnal dynamics and environmental stress effects on plant metabolism, e.g. due to low temperature. They will learn how to apply experimental data for computational analysis of complex biological systems. Students will learn to scientifically present and communicate their findings to researchers in the field of systems biology.
Responsible contact	Thomas, Nägele; Lisa, Fürtauer

Title	Practical course: Protein transport
Content	In this course we will learn how to isolate organelles from plants, translate proteins in vitro including radioactive labelling and prepare in vitro import assays. For further characterization we will also perform fractionation of organelles into their subcompartments and follow the procedure by biochemical techniques such as SDS-PAGE and immuno blots. Practicals skills in theses techniques are required to be accepted into the course.
Learning outcomes	Skills: - understanding of the molecular principles in respect to the content - presentation - scientific discussion and exchange
Responsible contact	Jürgen, Soll; Bettina, Bölter; Christopher, Carrie

Title	Practical course and Seminar: Mitochondria
Content	The practical course and the seminar will deepen the knowledge about mitochondrial biology and convey important state-of-the-art experimental approaches used to address scientific questions in the field of mitochondrial biology. This module is particularly recommended for students attending the lecture on mitochondrial biology, which is held in the summer semester. The following topics will be addressed experimentally by genetic, microscopy and biochemical approaches in the model organism S. cerevisiae in the practical part of the module and discussed in the seminar part: Mitochondrial morphology and dynamics visualized by live cell fluorescence microscopy, the importance of mitochondrial morphology and mitochondrial DNA for cell physiology, the mechanisms of protein import into mitochondria.
Learning outcomes	Students will learn new techniques in the lab and will further develop existing experimental skills. Students will learn how to address scientific questions and how to correctly analyse and interpret experimental results. In the seminar part, students will, furthermore, learn how to present scientific results to experts in cell

	biology and lay people and how to discuss new findings in the light of the current literature.
Responsible contact	Dejana, Mokranjac; Christof, Osman

Title	Practical course and Seminar: Regulation of plant metabolism
Content	In the seminar, students present and discuss different topics related to the investigation of plant metabolism, its regulation in response to environmental and physiological signals, and its significance for plant function and application. It builds on the Bachelor's level and aims to deepen and expand knowledge about (i) methods in plant metabolism research, (ii) regulatory mechanisms and signals, (iii) relevance for plant performance and function, and (iv) significance to optimize output traits and human application. The practical course will focus on the analysis of the carbohydrate metabolism in plants and its regulation. Investigations will be done in the context of metabolic regulation in response to environmental signals, regulatory sites and mechanisms, and the influence of carbohydrate metabolism on plant development. For this purpose, the students will unravel the genetic background of Arabidopsis knock-out lines applying selected approaches for phenotypic analyses, extraction and photometric quantification of metabolites, and determination of the redox-state of proteins by conserving western blots. The qualitative and quantitative data thereby generated will be evaluated and discussed by the students.
Learning outcomes	Seminar: The students will be able to present and communicate theoretical basics of plant metabolism research in a clear and unambiguous manner. They will gain expertise in exchanging information and ideas on a scientific level with experts and with laypersons, and to transfer knowledge to actual problems in plant biology and human society. Practical course: The students will strengthen their skills for future lab work. They will be able to communicate, apply and evaluate enzyme-based methods for metabolite quantification and methods to analyze post-translational redox-modifications of proteins. They will learn basic principles how to plan and perform experiments to analyze plant metabolism and to investigate redox regulation. For submission of

	a detailed lab report, the students are expected to put the obtained results in a biological context and discuss them critically, whereby they will train their scientific writing skills.
Responsible contact	Melanie, Paul; Peter, Geigenberger

Summer Term

Main Topic Genetics

Title	Lecture: Plant innate immunity
Content	A wide range of epidermal and epithelial cells are continuously exposed to a variety of pathogenic and symbiotic microbes. The survival of such rather hostile environments requires the evolution of refined molecular mechanisms by eukaryotic cells to discriminate between friend and foe. The aim of this lecture is the comparative elucidation of molecular principles that enable eukaryotic host cells to control microbial infections. We will discuss everything from genetic aspects of pattern evolution to structural aspects in receptor-ligand binding to biochemical aspects of kinase signalling that all contribute to host adaptation and are key for immunity. While we focus on plant-microbe interactions, you will see that there are common principles that have evolved in most eukaryotic systems.
Learning outcomes	At the end of the courses, students will be able to: - Explain concepts and prime examples of the plant immune system, both in principle and theory. - -Demonstrate a genetic, molecular, biochemical and cell biology understanding of plant-microbe interactions. - Discuss current knowledge and apply critical thinking to plant health and infectious diseases.
Responsible contact	Martin, Parniske; Silke, Robatzek

Title	Lecture: Genetics and More in Pharmaceutical Practise - Part II: Fundamentals in Drug Candidate Identification
Content	The lecture presents the fundamentals of the modern drug discovery process as established at small biotech and large pharmaceutical companies, with emphasis on biopharmaceuticals and biochemical, genetic, cell biological and pharmacological methods. These topics will be elucidated and accompanied by examples

	derived from important disease areas, such as metabolic diseases and cancer.
Learning outcomes	The scope of this lecture is geared primarily toward advanced bachelor and master students interested in applied Genetics. The overall aim of the lecture is to give a first impression about the complexity of modern drug finding and development and the professional opportunities for molecular and cellular biologists.
Responsible contact	Günter, Müller

Title	Lecture: Genetics of plant-microbe interactions in sustainable agriculture
Content	Within the course the students will learn the following contents: - Sustainable development goals and agriculture - Challenges in agriculture and impact on the environment - Fertilization, pesticides, herbicides, soil erosion, water use - aspects of plant physiology: uptake of nutrients and nutrient use efficiencies - Plant disease and pesticides in agriculture - Genetic resources for sustainable agriculture
Learning outcomes	Skills: - develop a basic understanding of current agricultural practices and their environmental impact - learn about the technological advances in agriculture and their limitations - understand the molecular hurdles and the genetic resources to develop sustainable practices in agriculture
Responsible contact	Martin, Parniske; Macarena, Marin; Dagmar, Hann

Title	Lecture: Eukaryotic gene regulation
Content	The lecture starts by revisiting the molecular principles of gene expression, from transcription initiation to the

	end of translation. It then covers the different levels of gene regulation, from transcriptional to post-transcriptional to translational and post-translational regulation. The true focus throughout the lecture is on the methods employed in modern biology to study gene expression at these different levels. The theoretical background of the techniques is covered, as are their practical limitations, their caveats and benefits.
Learning outcomes	Skills: - Theoretical knowledge on the molecular mechanisms underlying gene expression and its regulation. - Knowledge of key historical experiments and discoveries in the field of gene expression and regulation. - Knowledge of the fundamental differences between gene expression in pro- and eukaryotes. - Awareness and understanding of key molecular and computational methods that are employed in current research to study gene expression and gene regulation.
Responsible contact	Claude, Becker

Title	Seminar: Sustainable food production and global challenges
Content	Within the course the students will learn the following contents: - Plant Symbiosis and fertilization in agriculture - Plant disease and pesticides in agriculture - Genetic resources for sustainable agriculture
Learning outcomes	The students are capable of - literature search - discussion of scientific advances and societal impact - discussion of innovations in plant and agricultural sciences - writing of a scientific review
Responsible contact	Martin, Parniske; Macarena, Marin; Dagmar, Hann

Title	Seminar: Genetics and Society 1 - Biotechnology
Content	In the media we again and again hear buzzwords like „genefood“, „green genetics“ or „cloned animals“. In this seminar, we will not only discuss the scientific background but also ethical, economical and legal consequences of genetic research and its implementation.
Learning outcomes	Students will learn how to independently research broad and complex scientific topics: starting from the technological principles, they need to assess their political, moral, and ethical implications for society. Furthermore, students will learn how to reduce the complexity of these topics such that they can be presented in a relatively short time frame. Because the seminar topics are often controversial, the final goal of the seminar is to train the students in building an opinion and on scrutinizing it in discussing with the fellow students.
Responsible contact	Dagmar, Hann; Claude, Becker

Title	Practical course and seminar: Plant innate immunity
Content	This combined practical and seminar course will address two important biological questions: Week 1: What is the genetic distribution of MAMP recognition systems across the plant kingdom? And what are the genetic components of plant immunity that can be utilised in agriculture? Week 2: What are the genetic components of pattern-triggered immunity (PTI) missing in mutants of the model system A. thaliana? And what are the genetic components pathogens use to suppress plant immunity? We will use a combination of phenotyping and genotyping analysis to shed light on these questions. For phenotyping, we will use characteristic bioassays to monitor the induction of plant immunity such as the ROS burst and the trade-off between plant immunity and growth. For genotyping, we will provide primers to PCR amplify potentially mutated PTI genes. For genetic manipulation, we transgenically express PTI

	components of plant species in another species, and use virus-induced gene silencing (VIGS) to knock-down expression of key PTI genes. The course requires that students work in groups of two, and each group designs and conducts their own experiments. An introduction into good laboratory practice and experimental design will be given. You will plan your own experiments with the help of supervisors. Standard methods will be provided, which need to be adapted for your own experimental designs. Following your experimental design, you will conduct the experiments. Each experiment and the obtained results need to be recorded. An introduction into scientific protocol writing will be given. Two weeks after the practical course you need to submit your final protocols. Although experiments will be conducted in groups of two, each participant will need to write and submit their individual protocol. For successful completion of the course the protocols need to be approved by the supervisors. Feedback on the protocols will be provided by the supervisors. In addition to pedagogical seminars given by the supervisors, we will have 5 student seminars during the practical course. The seminars all address a relevant topic related to the experiments performed during the course, covering both technical aspects and scientific findings. Each group will select one topic and present it to all students in the form of an oral presentation. Yet, all students have to be prepared for each seminar and contribute to the discussion! Students will will provide feedback to all presentations. Supervisors will be available for the seminar preparations ahead of presentations.
Learning outcomes	At the end of the courses, students will be able to: - Explain techniques used in genetics, molecular plant biology and cell biology, both in principle and practice. - Design and conduct original research to address a problem in plant-bacterial interactions. - Demonstrate an understanding of original literature. - Apply problem-solving skills in laboratory experimentation and results conclusions. - Discuss current knowledge and apply critical thinking to plant health and infectious diseases.
Responsible contact	Martin, Parniske; Silke, Robatzek; Katarzyna, Rybak

Title	Practical course and seminar: Eukaryotic transcription and regulation
Content	Classical forward genetics continues to be a powerful approach to find genes involved in chosen biological processes and to obtain unequivocal information about gene products that provide the molecular basis of biological phenomena and/or functions. Research in molecular biology therefore strongly benefits from a good knowledge of genetic techniques. Traditionally, genes required for a chosen process are searched for by a forward genetic screen for aberrant phenotypes in a population of mutants, which is followed by the identification of the causal mutation by genetic mapping. Nowadays, the efficiency and speed of genetic mapping is highly increased by Next Generation Sequencing (NGS). NGS allows rapid and low cost sequencing of the complete genome of a given mutant and identification of the mutation by bioinformatic comparison of the mutant to the WT genome. Plants interact with a myriad of microorganisms of which some act as parasitic pathogens and others as beneficial symbionts. In this course we will focus on plant genetics of two root symbioses with microorganisms, the arbuscular mycorrhiza (AM) and the root nodule symbiosis (RNS). These symbioses are on one hand of agricultural interest because they provide mineral nutrients to the plant. On the other hand they are of great biological interest because they represent fascinating examples for reciprocal signal exchange between two organisms that leads to compatibility and extraordinary reprogramming and restructuring of the plant cell, that allows the intracellular accommodation of an "alien" microsymbiont
Learning outcomes	In this course you will learn how to use forward genetics to find mutated gene(s). By performing segregation analysis and genetic mapping of a segregating population of a symbiotic Lotus japonicus mutant you will gain practical hands-on experience in finding a candidate region in the genome in which your mutation resides. Furthermore, you will bioinformatically analyze NGS data to find the mutation underlying a symbiotic phenotype. We will perform segregation analysis and mapping with a nodulation mutant of which we do not know the locus responsible

	for the phenotype. Therefore, in this part of the course you will get involved in a "real research situation". Furthermore, you will learn how to extract nodulation signaling factors from Rhizobia and test their activity using a reporter-gene assay. You will also learn how to microscopically recognize features of rhizobial colonization (infection threads and nodules) and respective mutant phenotypes.
Responsible contact	Martin, Parniske; Dagmar, Hann

Title	Practical course and seminar: Molecular plant microbe interactions
Content	Within the course the students will learn the following contents: - Molecular biology and genetics of root nodule symbiosis and plant innate immunity - Root nodule symbiosis (cell biology, genetics and signaling) - genetic diversity in root nodule symbiosis
Learning outcomes	The students are capable of - literature search and presentation of scientific publications - cell biology of root nodule symbiosis (fluorescent microscopy, sections) - qPCR of plant defense marker genes - physiological response assays (ethylene reduction assay, ethylene production assay, ROS assay) - writing scientific reports (publication style)
Responsible contact	Martin, Parniske; Macarena, Marin; Dagmar, Hann

Title	Practical course and seminar: Drug target identification in tropical pathogens
Content	As example we will work on target identification for drug therapy of tropical diseases caused by kinetoplastid parasites (Sleeping sickness, Chagas disease, Leishminiasis). The main research focus of the Boshart lab is protein kinase A (PKA) signaling in Trypanosoma. The parasite PKA qualifies as promising drug target as it is essential for viability and virulence

	and different from mammalian PKA. In this practical course, we will characterize the ligand specificity of the regulatory T. brucei PKA subunit in vitro and in vivo. Moreover, we will perform in vivo assays for phenotypic characterization.
Learning outcomes	You will get hands-on experience on a number of methods including: - in vivo kinase reporter assay for compound screening - in vivo cell viability assay for compound screening - protein-protein interaction analysis using a split - luciferase assay (NanoBiT - growth curves and protein expression analysis in trypanosomes - motility analysis and live cell tracking using Fiji (ImageJ - computational analysis of protein-ligand interaction using Pymol
Responsible contact	Michael, Boshart; Sabine, Bachmaier

Main Topic Human Biology - Epigenetics

Title	Lecture: Human Biology - The Good, The Bad & The Ugly - from Stem Cells over Cancer Cells and Aging Cells
Content	Within the course the students will learn the following contents: - Embryonic Stem Cells, Adult Stem Cells & iPS cells - The Hallmarks of Cancer - Tumorsuppressorgenes & Oncogenes - Metastasis and Invasion - Cancer Therapies - New therapeutic approaches - Histone Modifications - Cancer of the hematopoietic system - Leucemia - Aging
Learning outcomes	The students are capable of - knowledge of the basic molecular principles of the content above - understanding of the regulatory mechanisms underlaying these principles - transfer knowledge to related biological systems

	- troubleshooting of experimental approaches
Responsible contact	Daniela, Meilinger; Heinrich, Leonhardt

Title	Lecture: Epigenetics
Content	"Epigenetics" is a lecture series that is team-taught by several instructors that cover basic background information as well as currently ongoing research topics in the field of epigenetics, involving DNA methylation, histone modification, polycomb, non-coding RNA, epigenetic regulations and networks.
Learning outcomes	The students are proficient in the areas of epigenetics, involving DNA methylation, histone modification, polycomb, non-coding RNA, epigenetic regulations and networks and are able to depict basic principles and transfer knowledge in an exam situation. Students obtain the fundamental knowledge required to participate in further specialized courses and to understand and critically evaluate primary literature in these areas of research. Students are equipped with the basic knowledge prerequisite to scientific research in these topics.
Responsible contact	Daniela, Meilinger; Heinrich, Leonhardt

Title	Seminar: BioImaging Techniques
Content	The following topics will be covered - Fluorescent Antibodies, Nanobodies and so on - Artefacts in sample preparation - Basics of fluorescence microscopy - Confocal microscopy - Spinning disk and light sheet microscopy - Structured illumination microscopy
Learning outcomes	Skills: - understanding of the limits of resolution - overview over state-of-the-art imaging techniques

	- Pros and cons of the different microscopic techniques - scientific discussion and exchange-feedback
Responsible contact	Daniela, Meilinger; Hartmann, Harz

Title	Seminar: Same but different - epigenetics in plants and humans
Content	Participants in the seminar "Same but different - epigenetics in plants and humans" obtain detailed knowledge on the similar and different epigenetic mechanism in plants and humans. The seminar is team-taught by plant- and human-biologists and aims to understand underlying evolutionary conserved epigenetic mechanism. Students are working in teams and should work out similarities/differences, with one student focusing on the plant and the other student focusing on the human mechanism. Content: - History of Epigenetics Discoveries - DNA Methylation Enzymes - DNA De-methylation - Epigenetic Changes during Development - Regulation of DNA Methylation by small RNA's - Imprinting - Transgenerational Epigenetics
Learning outcomes	Skills: - understanding of the molecular principles in respect to the content - relevant literature search - presentation skills - teamwork - scientific discussion and exchange - feedback
Responsible contact	Daniela, Meilinger; Bettina, Bölter

Title	Practical course: Tumorepigenetics (incl. Seminar)
Content	Participants in "Tumorepigenetics" obtain basic knowledge of DNA methylation, histone modifications and polycomb. During the scope of the practical course

	participants are introduced to classic DNA methylation analysis techniques such as bisulfite modification and COBRA, as well as basic cell culture handling, RTPCR for expression profiles and fluorescence microscopy. During the course, the students will treat 3 different human carcinoma cell lines with different epigenetic inhibitors, isolate genomic DNA and perform a COBRA for methylation analysis. In addition, they perform antibody staining for methylcytosine and different histone modifications for microscopic analysis.
Learning outcomes	Students can apply theoretical and practical knowledge to approach biological questions in independent work. Students obtain skills for future lab work in the field of epigenetics, in particular in preparation for their master's thesis. Students are well trained in good general lab practice, including standard safety procedures, precise handling of chemicals and instruments, conscientious documentation of lab procedures, and obtain skills in specialized techniques such as cell culture of mammalian cells, genomic DNA isolation, bisulfite treatment, COBRA, Real Time PCR, antibody staining of fixed cells and fluorescence microscopy. Students practice critical evaluation and interpretation of data as a basis for careful and relevant conclusions. In working in small lab groups (2 students), social skills (teamwork, cooperation, fair play, work delegation, mutual respect), communication skills (rapport with instructors and fellow students, presentations, written lab reports), as well as organizational skills (efficient planning, documentation) are refined. Students learn excellent scientific methods in written data presentation, including well-founded introduction to the topic, documentation, interpretation and discussion of the results. These skills are particularly aimed at preparing students for thesis writing and scientific publications.
Responsible contact	Daniela, Meilinger; Heinrich, Leonhardt

Title	Practical Course: Light microscopy, from bright field to superresolution

Content	The students will learn the theory and practical application of light microscopic techniques, starting with the basics of "classic" techniques such as bright field Koehler Illumination, phase contrast, dark field, differential interference contrast (DIC) and fluorescence microscopy. We then move on to more advanced topics such as confocal laser scanning microscopy, multi-photon microscopy and super resolution microscopy. To do so, we will mainly use the equipment of the Core Facility Bioimaging at the Biomedical Center. These techniques are applied to a variety of samples from fixed tissue sections to live cells and intravital microscopy. Small groups of students will use image processing software to generate a presentation with the images and movies recorded.
Learning outcomes	With this broad overview the student will be capable to determine advantages and disadvantages of various light microscopic approaches for different experimental settings and thus to select and apply the best approach for a given question.
Responsible contact	Steffen, Dietzel

Title	Practical course: Bioimaging (incl. Seminar)
Content	In-depth introduction to relevant methods for basic and advanced light-microscopy techniques. Participants are introduced to classical microscopy techniques like widefield, phase contrast and dark-field. In parallel, participants get a brief introduction to cell culture and are preparing their own fluorescently labeled cell samples using direct- and immunolabeling techniques. Based on these samples several advanced microscopy techniques are used for image acquisition. Technological possibilities are evaluated based on the acquired and processed images. Emphasis is placed on the relevance and hands-on practice with these microscopic techniques as well as the interpretation and presentation of data.
Learning outcomes	Students are well trained in sample preparation and basic as well as advanced optical microscopy techniques. They obtain the fundamental knowledge required to understand the individual possibilities and limitations of these techniques. Obtained skills are a

	prerequisite for a successful selection and utilization of optical microscopes, e.g. during their master's thesis.
Responsible contact	Daniela, Meilinger; Heinrich, Leonhardt; Hartmann, Harz

Main Topic Human Biology – Human Genomics

Title	Lecture: Human genomics II
Content	This lecture covers advanced aspects of human genomics and their biomedical relevance. Building partially on the topics covered in Human Genomics I, it focuses on using human genomics to map disease genes and to understand and diagnose cancer.
Learning outcomes	The students know how human genomics is used to study human diseases and cancer.
Responsible contact	Wolfgang, Enard

Title	Seminar: Current topics in Statistical Genomics
Content	In the seminar, the students critically present and discuss current publications related to genomic analyses. This includes papers related to experimental and computational aspects of single-cell RNA-sequencing, evolutionary genomics or cancer genomics that are relevant int the context of current Research of the AG Enard and AG Hellmann.
Learning outcomes	The students will be able to extract and judge relevant information also from complex literature and to exchange information and ideas on a scientific level with experts in Genomics.
Responsible contact	Wolfgang, Enard; Ines, Hellmann

Title	Seminar: Genomics of Adaptation and Speciation
Content	Species formation has fascinated evolutionary biologists for centuries. How does natural selection lead to local adaptation? Can genetic incompatibilities maintain species borders? How do these processes interact during the continuum of species formation? Answers to these questions have remained unanswered largely due to the lack of genomic tools that can be applicable across species. The recent advent of high-throughput sequencing has unlocked these limitations and allows applications to virtually any kind of organism. In this seminar, we will discuss the most recent papers defining new benchmarks in genomics of speciation. We will discuss foundational theory supporting new research questions, advantages of current genomic methodologies, and the limitation defining future advances of the field. Specifically, we cover eleven topics: 1. Demographic history of divergence; 2. Post-zygotic intrinsic isolation; 3. Cyto-nuclear incompatibilities; 4. Pre-zygotic isolation; 5. Genetic basis of adaptation; 6. Postzygotic extrinsic isolation; 7. Chromosomal speciation; 8. Genomic landscape of speciation; 9. Ecological speciation; 1-. Evolutionary consequences of hybridization; 11. Hybrid zones.
Learning outcomes	In this master-level course, the students will: - Present and discuss concepts from diverse fields that contribute to evolutionary biology (genomics, genetics, behaviour, ecology, etc…) - Get familiar with long standing questions and theory on speciation research; - Understand the advantages and limitations of new genomics methods; - Identify opportunities for future research
Responsible contact	Jochen, Wolf; Ricardo, Pereira

Title	Seminar: Induced pluripotent stem cell technologies
Content	The discovery of induced pluripotent stem cells in 2--6 revolutionized human cell biology. Milestone papers in this field and examples of the biological and medical applications will be presented and discussed.
Learning outcomes	The students will get an overview on the field of induced pluripotent stem cells and will be able to

	understand, present, discuss and critically judge current literature in the field.
Responsible contact	Wolfgang, Enard; Johanna, Geuder; Micha, Drukker

Title	Practical course (incl. lectures): Essential skills in the analysis of high-throughput genomic data
Content	Within the course the students will learn the following contents: - Technologies and application protocols of high-throughput sequencing - Areas of application and study design - Online databases - UNIX like operating systems - Use of remote computer clusters - Bash programming - Bioinformatic principles - Data formats - Data processing
Learning outcomes	Students get familiar with the terminology, technological and algorithmic basis of research using high-throughput sequencing technology. They obtain an understanding of appropriate study design, get familiar with established types of data encoding and acquire hands-on experience with basic components of bioinformatic analyses pipelines.
Responsible contact	Jochen, Wolf

Title	Lecture and Practical course: Pretty plots - Visualisierung statistischer Daten
Content	Data Science is not only a buzz word, but it is becoming the key to success in many fields of biology. In this course you will learn basic data science. We will repeat and expand basic statistical concepts and apply them interpret published data and as well as to analyse your own data. Most importantly, the course teaches how to visualize statistical data as beautiful figures generated with R and ggplot2.

Learning outcomes	The students will be able to handle and plot data using the statistical scripting language R. This is a key qualification for modern, quantitative biology and will provide the necessary basics to apply and extend these skills when handling and plotting data in scientific projects.
Responsible contact	Wolfgang, Enard; Ines, Hellmann

Main Topic Microbiology

Title	Lecture: Bacterial Cell Biology
Content	The lecture series is devoted to microbial cell biology. Recent advances in microbiology have demonstrated that prokaryotic cells have a highly organized and dynamic suvcellular architecture. Therefore, the lecture will introduce into the current knowledge of bacterial and archaeal fine structure. It will provide an overview over modern light, fluorescent and electron microscopic techniques for studying microbial cellular architecture. Among major topics are the structure and function of bacterial compartments, organelles, appendages and cytoskeletal elements. Key cellular processes such as prokaryotic cell division and differentiation will be highlighted. A further focus will be on prokaryotic cell walls including peptidoglycan architecture as well as S-layer proteins. The last part of the lecture will provide an overview about microbial unicellular eukaryotes and some aspects and developments of synthetic microbiology.
Learning outcomes	The lecture will lead to a deeper understanding of microbial cell biology building on already existing general knowledge about classical microbiology and cell biology. Students will learn which methods can be used to investigate the cell biology of small unicellular organisms. This should enable the students to develop new and own ideas and experiments in this and realted fields and to carry out practical courses, research internships or their master thesis in this scientific area.
Responsible contact	W2 Professur Zelluläre Mikrobiologie, N.N.; Andreas, Klingl

Title	Lecture: Molecular virology (Part II: general and specific virology)
Content	"Molecular Virology II" covers basic principles of virology with respect to virus-induced cell transformation, virus evolution, infection types, strategies, virus vectors, molecular diagnostics, vaccines, development of antivirals, and provides an introduction to major DNA virus families.
Learning outcomes	In conjunction with course 2, the students gain an overview of the major RNA virus families, their molecular features, replication strategies of viruses, major discoveries in cell biology made by the study of viruses, principles of molecular virology, and strategies for the development of antiviral inhibitors, among others. This lecture series puts students in the position to appreciate the significance of virology on biology and provides important knowledge pertaining not only to molecular virology but also to human biology and cell biology which is useful for future independent research work.
Responsible contact	Ruth, Brack-Werner

Title	Seminar: Current methods in electron microscopy
Content	The seminar covers the most recent and advanced developments and inventions in high-resolution (cryo) electron microscopy and closely related areas. It deals with the variety of advanced (cryo) methods applied in electron microscopy in general an which are partially also applied at our institute with a main focus on the preparational background. These are methods like high-pressure freezing, imunogold localization, 3D structure of cells, SBF-SEM, FIB/SEM-tomography, TEM- and STEM-tomography or single particle analysis. In the seminar, students are working on a selected topic which includes the discussion on a current publication applying the respective method highlighting the advantages and disadvantages of the application.
Learning outcomes	Within this seminar, students can intensify and deepen the knowledge gained in the lecture 'An introduction to electron microscopy'. They will get insight into the application of advanced methods, experience

	limitations and shortcomings of the techniques. After the seminar, students will be able to understand the technical principles and to discuss about the presented methods with other researchers in that scientific field.
Responsible contact	Andreas, Klingl

Title	Seminar: Microorganisms and Humans: a not entirely harmonious relationship
Content	In the first part of the seminar the students will give presentations on techniques used in cell biology. By going into detail on techniques used in the analysis of cell structures, the students will learn to have a deeper understanding of the abilities of modern science, as well as its borders. In the second part of the seminar the students are introduced to some fundamental principles and applications of synthetic microbiology. Current primary publications covering engineering of synthetic regulatory circuits and potential practical applications of the designed bacterial strains will be presented by the participants as oral presentations to the whole group. Preparation of these presentations will be supported by the students' independent research of the topic, assisted by the course instructor. A special emphasis is placed on standard methodologies in synthetic biology, levels of regulatory control, theory of transcriptional logic as well as safety aspects in genetic engineering.
Learning outcomes	Scientific publications will be presented to the group together with accessory information necessary for understanding. Students thereby practice to prepare sophisticated scientific work for a professional audience and to assess and interpret data critically as a basis for careful and relevant conclusions. The group will discuss the scientific work presented, as well as the lecture itself. In that way students improve their presentation and communication skills particularly in respect to thesis writing, scientific publications and defense. The students will gain detailed insight into sophisticated techniques used in cell biology. The students are exposed to a relatively new field in biology, i.e. synthetic biology, and gain an understanding of how principles of classical engineering can be applied to living systems. They

	enhance their skills in critical thinking and scientific argumentation from group discussions on experimental as well as ethical aspects of synthetic biology.
Responsible contact	Kirsten, Jung; Frank, Landgraf

Title	Practical Course: Methods in transmission electron microscopy and their application
Content	Within this practical course and the corresponding seminar, the students will learn how to perform the preparation of a variety of biological specimens for subsequent transmission electron microscopy. Samples will include plant material, photosynthetic algae and prokaryotes. The applied methods will include chemical and cryo-fixation, embedding and thin section, negative staining, immunogold localization and 3D electron microscopy (e.g.: TEM tomography). As a final part of the course, data processing and analysis will play a central and important role.
Learning outcomes	The practical course will give the students the possibility to practically learn the application of the diverse sample preparation methods for electron microscopy and the subsequent investigation of the samples in the respective microscope. It should enable the students to develop own ideas and experiments in this and realted fields and to carry out research internships or their master thesis in this scientific area.
Responsible contact	Andreas, Klingl; Carolin, Pickl

Title	Practical course and Seminar: Bacterial Cell Biology
Content	Bacterial cells have a high degree of internal organization. Hence, macromolecules are often precisely localized to subcellular compartments. In this course we will use genetic tools to construct fluorescent fusions to cytokinetic or cytoskeletal proteins and use fluorescence microscopy to analyze protein localization and dynamics in vivo. Further, these proteins will be purified using fast protein liquid

	chromatography and their function will be analyzed in vitro using classical biochemical methods.
Learning outcomes	Students who successfully completed this module are able to work on a complex research project in bacterial cell biology. They can address scientific questions experimentally and analyze experimental results related to microbial cell biology including mechanisms of bacterial cell division and protein localization and function.
Responsible contact	W2 Professur Zelluläre Mikrobiologie; N.N.

Title	Advanced lecture on (cryo) electron microscopy
Content	The lecture builds on the lecture 'An introduction to electron microscopy'. It will deepen the knowledge about the physical principles in electron microscopy and how one can use this for improving the resolution limits in (cryo) electron microscopic applications like TEM-, STEM- and FIB/SEM-tomography, electron crystallography or single-particle analysis. Amongst others, the lecture will deal with topics like electron guns, detectors, EM lenses, energy filters, image formation, fourier transforms, reciprocal space and electron waves, convolution and cross-correlation, contrast (contrast transfer function, CTF) and CTF-correction.
Learning outcomes	The lecture will lead to a deeper understanding of the mathematical and physical background of resolution and how it can be influenced and improved in electron microscopy. Following this lecture, students will be able to develop new and own ideas and experiments not just in the application of already existing techniques but also in the developmental area, e.g. correctors for spherical aberration in TEMs. Attendees of the lecture will not just be provided with broad expertise but they will also be ideally primed as potential future employees in (electron) microscopy companies and related fields.
Responsible contact	Andreas, Klingl

Main Topic Cell Biology

Title	Lecture: Current Topics in Cell and Developmental Biology
Content	"Current topics in Cell and Developmental Biology I" is a lecture series that is team-taught by several instructors that cover basic background as well as research currently ongoing in their fields of expertise (post-transcriptional gene regulation/splicing, mitochondrial biogenesis and dynamics, dosage compensation, muscle development, genome analyses, apoptosis).
Learning outcomes	The students are proficient in the areas of post-transcriptional gene regulation/splicing, mitochondrial biogenesis and dynamics, dosage compensation, muscle development, genome analyses, and apoptosis and are able to depict basic principles and transfer knowledge in an exam situation. Students obtain the fundamental knowledge required to participate in further specialized courses and to understand and critically evaluate primary literature in these areas of research. Students are equipped with the basic knowledge prerequisite to scientific research in these topics.
Responsible contact	Charles, David; Dorothee, Dormann; Nikola, Wagener

Title	Lecture: Mechanism of animal development (vertebrates)
Content	This course covers fundamental mechanisms of animal development, as determined using the model invertebrates, Drosophila melanogaster and Caenorhabditis elegans. Basic principles are discussed, as are the experimental methodologies that have led to key discoveries.
Learning outcomes	The students are proficient in the basic developmental biology (embryology and fate maps) of Drosophila and C. elegans. Students are familiar with the genetic, molecular, and experimental methods used to elucidate principles of development.

	Students are able to interpret novel data sets, formulate hypotheses, and suggest experimental approaches that could be used to test these hypotheses. Students are able to integrate knowledge from lecture with information obtained through online data searches.
Responsible contact	Tamara, Mikeladze-Dvali; Prisca, Chapouton; Anika, Böttcher

Title	Lecture: Membranes - biological and physical aspects
Content	Membranes are essential functional components of many cellular functions. The lecture gives a detailed overview over the molecular structure of biomembranes, including the basic physical and biological principles of membrane proteins and lipids, their synthesis and transport within the cell. It furthermore explains the functional role of membranes in different cellular processes.
Learning outcomes	At the end of the lecture the students have obtained fundamental knowledge about the molecular structure and composition of biomembranes in a cellular context. They are able to understand the functional (and not only structural) role that membranes play in many cellular processes.
Responsible contact	Thomas, Nägele

Title	Lecture: Mitochondrial Cell Biology
Content	The lecture builds on the Bachelor's level, the module aims to significantly deepen and expand knowledge and understanding in the areas of Mitochondrial Biology. The lecture will also present latest progress in mitochondrial biology and educate students about state-of-the-art experimental methodologies in the field of cell biology. The lecture series will lead the students to the frontiers of knowledge and present them with open questions in mitochondrial biology. The following

	topics are addressed: Mitochondrial energy metabolism, the endosymbiotic theory, mechanisms of mitochondrial ultrastructure maintenance, mechanisms of mitochondiral protein import, mitochondrial lipid homeostasis, maintenance and expression of the mitochondrial genome (mtDNA), mitochondrial diseases, mitochondrial dynamics, mitochondrial quality control
Learning outcomes	The students will be able to integrate knowledge and deal with the complexity of Mitochondrial biology. Students will learn how to address scientific problems in the field of mitochondrial biology. Students will also learn about remaining big open scientific questions in the field of mitochondrial biology.
Responsible contact	Christof, Osman

Title	Seminar: Animal regeneration
Content	Topics related to animal regeneration are assigned to each student. These cover regeneration in invertebrates including cnidarians (hydra), planarians, echinoderms and in vertebrates, e.g amphibians and mammals. The main emphasis is on molecular mechanisms involved in these regeneration processes. Using recommended literature and resources, and with regular consultation with the instructor, students independently research the topic. The seminar requires an oral presentation of the topic to the entire group with subsequent general discussion.
Learning outcomes	Students are introduced to current advances in our understanding of molecular mechanisms in animal regeneration, and can discuss this in a broad context. Participants are introduced to library and internet resources and are encouraged to independently research them to cover their chosen topic. They learn to critically evaluate historical and current experimental data and introduce the state of the art of their theme to the group. They are proficient in presentation skills using mainly power point and can engage in a broader discussion within the group.
Responsible contact	Angelika, Böttger

Title	Seminar: Molecular and ecological aspects of biotechnology with micro-algae and cyanobacteria
Content	Participants get insights into current work in the field of molecular biology, biotechnology and ecology of cyanobacteria, algae, and cell organelles. They present results of a recommended publication in an oral presentation according to excellent scientific practice, to the entire group. After each talk, the subject is discussed in the whole group and the presenter is supposed to answer questions.
Learning outcomes	Students are introduced to current literature and learn how to independently research a topic. They improve their presentation skills and learn how to present scientific data. In addition, the discussion of the topics with other participants trains a critical review of illustrated data which is the basis for good scientific practice.
Responsible contact	Herwig, Stibor; Jörg, Nickelsen

Title	Seminar: Mitochondrial dynamics in health and disease
Content	Mitochondria are essential organelles that play important roles in various processes, such as energy production, cell signaling and apoptosis. Mitochondrial shape, quality and biomass are regulated by a balance between mitochondrial biogenesis and mitochondrial degradation as well as a balance between mitochondrial fusion and mitochondrial fission. During this seminar, we will see how the study of these basic biological processes can increase our understanding of neurodegenerative diseases. Conversely, we will see how the study of a particular disease, the Parkinson's disease, has increased our understanding of a basic biological process, mitochondrial quality control. This seminar is a 2-days block seminar during which each student will present a publication. All the publications have been selected around a unifying theme, in a way that publications presented by some students will be connected to publications presented by other students. This organization helps to foster group discussion. Furthermore, the students will be exposed to "old" as well as more recent publications, which will

	give the students an idea of the evolution of the experimental approaches and scientific knowledge.
Learning outcomes	With this course, the students will improve their skills on (i) how to read a publication with a critical eye, (ii) how the basic knowledge they learn in lectures was actually scientifically discovered, (iii) how to present their findings to an audience and finally (iv) how to ask questions.
Responsible contact	Charles, David; Stephane, Rolland

Title	Seminar: Signalling in development and disease
Content	Many human congenital diseases arise from aberrations of developmental processes. This seminar explores selected developmental concepts, their underlying molecular mechanisms, the link to human diseases and vertebrate evolution. The seminar is an extension of some of the topics covered in the lecture Mechanisms of Animal Development.
Learning outcomes	Students will acquire an in depth knowledge about the state of the art of selected developmental concepts and their underlying molecular mechanisms. By presenting a selected scientific paper students will train their presentation and communication skills. The course has an emphasis on critical reading and analysis of primary scientific literature. While analyzing the primary literature students will explore how scientists pose their questions, which methods they use to answer them and how they come to their conclusions. Students will be encouraged to critically evaluate whether the presented data lead to the conclusions, to think about follow up questions and to actively participate in discussions.
Responsible contact	Tamara, Mikeladze-Dvali

Title	Seminar: Evolutionary cell biology of plants
Content	The seminar introduces to topics of current research in the field of plant biology. The topics which are

	addressed are: Plant evolution; Cell biology; Stress physiology; Plant development and ecology.
Learning outcomes	Students will be able to summarize and critically discuss literature on research in current plant biology. They will be able to communicate their conclusions in a clear and scientific manner for exchange of information and ideas with experts in the field of plant evolution and cell biology.
Responsible contact	Thomas, Nägele; Lisa, Fürtauer

Title	Seminar: The mitochondrial genome - from its discovery to three-parent-babies
Content	In this seminar, students will be provided with topics (rather than single publications) sorrounding the biology of the mitochondrial genome (mtDNA). The students task will be to provide a presentation in which the given topic is being introduced and discussed. The goal is to stimulate lively discussions among participants and to identify open questions in mtDNA biology. The seminar is particularly useful in combination with the lecture on mitochondrial biology and will deepen the following aspects on the mitochondrial genome: Discovery of mtDNA, Visualization of mtDNA, Inheritance of mtDNA, mtDNA replication, mtDNA packaging, mtDNA expression, mtDNA related diseases, mtDNA and ageing, mtDNA in reproductive medicine and three parent babies.
Learning outcomes	The students will be able to independently educate themselves and others about a current topic in (cell) biology. Furthermore, students will learn to identify open scientific questions and hone their skills in communicating scientific ideas with cell biology experts and lay persons.
Responsible contact	Christof, Osman

Title	Practical course: Molecular biology and biochemistry of photoautotrophic microorganisms

Content	The course imparts knowledge about the principles of plastidic gene expression. Students will work with the unicellular green alga Chlamydomonas reinhardtii and analyze different strains with regard to their gene expression at the level of transcription as well as translation. Applied methods comprise reporter gene expression analysis, nuclear transformation of C. reinhardtii, and testing of growth under photoautotrophic conditions. Emphasis will lie on molecular methods, like the isolation and detection of DNAs (Southern blot), RNAs (Northern blot) as well as proteins (Western blot), respectively. Based on the performed phenotypical and molecular analyses of different strains the students will be able to draw conclusions on the identity of the investigated mutants.
Learning outcomes	After participation in this course, students will know how to combine different methods to address a specific scientific question. They will be able to summarize, present, and discuss the outcome. Furthermore, they can distinguish different regulatory levels of gene expression and integrate the obtained results in an overall context. Methodically, they have deepened skills in Southern, Northern and Western analysis and will have gained insights into basic working practice with unicellular green algae.
Responsible contact	Jörg, Nickelsen

Title	Practical course: Methods for protein characterization
Content	2-week course on several methods applied for the in vitro characterization of proteins including: protein overexpression in E.coli, purification of recombinant proteins using chromatography and an FPLC system, isoelectric focusing, isolation of stromal proteins from plants, in vitro protein-protein interactions - experiments are performed in groups of two following given protocols - documentation and interpretation of results - presentation of the results in written form - talk about a topic related to the practical part: e.g. chromatography methods, crystallization approaches, antibody generation and chloroplast redox biology
Learning outcomes	Students who successfully completed this module are able to… - design and handle experiments with the techniques mentioned above (specifically they

	are able to work an ÄKTA FPLC system and the Unicorn software) - expand their theoretical knowledge on biochemical protein related methods to a practical level - analyze experimental results - prepare figures from the obtained data and describe aim and outcome of the experiments - Selecting and summarizing literature - Setting up a power point presentation - Speaking in front of other students within a limited time
Responsible contact	Jürgen, Soll

Research courses and Research projects

Title	Research course: Advanced light microscopy
Content	Participation in current research, lab work, data interpretation.
Learning outcomes	The practical research course requires independent planning, organization and performance of experiments, including interpretation and documentation of results.
Responsible contact	Steffen, Dietzel

Title	Research course: Bacterial cell entry
Content	- root nodule symbiosis (cell biology, genetics and signaling) - genetics and genomics of rhizobia - genetic diversity in root nodule symbiosis
Learning outcomes	Skills: - literature search and presentation of scientific publications - cell biology of root nodule symbiosis (fluorescent microscopy, sections) - mutagenesis

	- golden-gate cloning - writing scientific reports (publication style) - scientific data presentation
Responsible contact	Macarena, Marin

Title	Research course: Cell and developmental biology of animals
Content	Individual research topics are offered. - -Hydra head regeneration and stem cell differentiation, - -the effect of developmental pathways on pattern formation in Hydra (Notch, Wnt, BMP-signalling) - the function of an Fe(II) and 2-oxoglutarate dependent dioxygenase (Jmjd6) in Hydra and in human cells - Jmjd6 in hypoxia
Learning outcomes	Students should become proficient in experimental laboratory work, designing and documenting such work, use of biochemical and imaging techniques. Communication skills (rapport with instructors and fellow students, presentations of theoretical background and results, written lab reports), as well as organizational skills (efficient planning, documentation) are refined. Students will be introduced to good laboratory practical issues.
Responsible contact	Angelika, Böttger

Title	Research course: Cellular mechanisms in reproductive medicine
Content	- 8-week research project, full-time (approx. 8 hours per day) - experience the daily life of scientific research in a medium-size team (this includes working in the lab under supervision and also

	independently, joining lab meetings and discussions) - practical work will focus either on a topic in reproductive medicine dealing with human ovary or testis, monkey or mouse models, or with immortalized cell lines - independent execution and analysis of experiments - interpretation and discussion of the results within the group - literature research - presentation of the research project (talks at lab meetings, written report)
Learning outcomes	Students who completed this module obtained insights into (specific methods may vary dependent on the research project) - current research topics in molecular reproductive medicine with medical relevance - cell culture techniques using primary and/or passaged cells or permanent cell lines - pharmacological studies - molecular analysis of signaling pathways - qPCR - different visualization methods (immunhistochemistry, immunfluorescence) - design and performance of scientific projects related to specific clinical questions - experimentation to address scientific questions and analysis of experimental results
Responsible contact	Annette, Müller-Taubenberger

Title	Research course: Cellular mechanisms of neurodegeneration
Content	Participation in current research, lab work, data interpretation.
Learning outcomes	The practical research course requires independent planning, organization and performance of experiments, including interpretation and documentation of results.
Responsible contact	Dorothee, Dormann; Christof, Osman

Title	Research course: Centrosome dynamics
Content	Students will actively participate in our ongoing research on centrosome dynamics using the nematode C. elegans as a model organism. Centrosomes are the major microtubule organizing centers of animal cells. Centrosome components have diverse functions in many different cell biological processes, ranging from cell division to cell polarity and signaling. Deregulation of centrosomal components can lead to human conditions as cancer and microcephaly. Therefore, our research is focused on deciphering molecular mechanisms regulating centrosome dynamics in different tissues of a living organism.
Learning outcomes	Students will acquire practical skills in molecular biology and biochemical tequniques, C. elegans genetics and state of the art microscopy approaches. Students will learn how to acquire data, analyze the data and how to present their results in an oral and written way. During the course students are expected to actively participate in group meetings and journal clubs.
Responsible contact	Tamara, Mikeladze-Dvali

Title	Research course: Comparative Primate Genomics
Content	Wet-lab or wet-lab/computional projects related to the evolution of molecular circuitry within the AG Enard and AG Hellmann. This includes cancer genomics, single-cell RNA-seq technologies, molecular neurobiology and primate iPS cells.
Learning outcomes	Students learn to independently plan and organize research work, perform and troubleshoot experiments, interpret and document results and communicate and discuss findings within the group.
Responsible contact	Wolfgang, Enard; Mari, Ohnuki

Title	Research course: Computational Genomics
Content	Purely computational projects related to the evolution of molecular circuitry within the AG Hellmann. We focus on testing and developing computational methods for the statistical analysis of gene expression networks in evolution. Most of our work is done in with R.
Learning outcomes	Students learn to independently plan and organize research work, perform and troubleshoot computational experiments, interpret and document results and communicate and discuss findings within the group.
Responsible contact	Ines, Hellmann

Title	Research course: Current topics in ultrastructural research in electron microscopy
Content	The students will get insight into various preparation and fixation methods for transmission and scanning electron microscopy. They will be trained in the respective equipment and microscopes. In addition, they will broaden their knowledge about the ultrastructure of plants, microbes or any other kind of cells and tissues snd the techniques, how thesecells can be investigated. A major focus will be on the 3-dimensional ultrastructure and correlative light and electron microscopy (CLEM). Therefore, the students will also be trained in advanced methods like TEM- and FIB/SEM-tomography, subsequent image processing and analysis.
Learning outcomes	The research course will lead to a fundamental understanding of the various preparation techniques and their necessity for the project. Furthermore, the students will gain general knowledge of the working principle of an electron microscope and the additional equipment used for sample preparation. In the end, they will be able to apply the methods independently and it will be possible for them to critically evaluate their results and especially their micrographs and discuss these results with other researchers within the field of electron microscopy and structural research. Furthermore, research students will be able to estimate a potential application of the used methods in their own future projects.

Responsible contact	Andreas, Klingl

Title	Research course: Current topics in ultrastructural research on plant-microbe interactions
Content	The students will get insight into various preparation and fixation methods for transmission and scanning electron microscopy. They will be trained in the respective equipment and microscopes. In addition, they will broaden their knowledge about plant-microbe interactions and the techniques, how these associations can be investigated. A major focus will be on the 3-dimensional ultrastructure of the involved host and symbiont cells. Therefore, the students will also be trained in advanced methods like TEM- and FIB/SEM-tomography, subsequent image processing and analysis. Furthermore, the students will get insight into respective literature research, experimental design, data documentation and interpretation and the final project presentation.
Learning outcomes	The research course will lead to a fundamental understanding of the various preparation techniques and their necessity for the project. Furthermore, the students will gain general knowledge of the working principle of an electron microscope and the additional equipment used for sample preparation. In the end, they will be able to apply the methods independently and it will be possible for them to critically evaluate their results and especially their micrographs and discuss these results with other researchers within the field of electron microscopy and structural research. Furthermore, research students will be able to estimate a potential application of the used methods in their own future research projects.
Responsible contact	Andreas, Klingl

Title	Research course: DNA-Repair
Content	Participation in research questions of radiobiological lab. We investigate effects of irradiation in 2D and 3D

	tumour cell models. Methods: Tissue culture, invasion assays, bright-field and fluorescence microscopy, image analysis, kryo-sectioning and staining, immunofluorescence, Western Blot analysis, cloning, generation of genetically modified cell lines. Participants are expected to work 8 weeks, approx. 8 hours per day and they will join lab meetings to present their data, as well as the lab journal club to present a relevant paper. At the end the research outcome will be presented in written form in a protocol.
Learning outcomes	Students who successfully completed this research course are able to address scientific questions experimentally and analyze experimental results. They learned to independently design and perform small scientific projects related to the topic DNA-repair on a professional level. They experienced the importance of reliable documentation and analysis of experimental data and they learned to present the research in professional, audience-adjusted language.
Responsible contact	Anna, Friedl

Title	Research course: Human biology, epigenetics
Content	Research projects related to cancer epigenetics, stem cell biology & epigenetic events in differentiation processes, Antibody-Drug Conjugates, Antibody Generation and Advanced High-Resolution Microcopy. Student project is based on current and latest research and designed closely with the direct supervisor in the lab (PostDoc, PhD student) experience the daily life of scientific research this includes working in the lab under supervision and as soon as ready students are expected to work independently joining lab meetings and discussions independent literature research design of a research schedule document, interpret and discuss the results of experiments in scientific language documentation in a lab journal analysis of experiments presentation of the research project both orally and in written form
Learning outcomes	Students who successfully completed this module are able to…

	- work on a complex research project - strengthen practical lab skills to be able to work independently - independently design and perform small scientific projects related to the topic of the module on a professional level - address scientific questions experimentally and analyze experimental results - apply the learning contents and skills from pre-connected modules and deepen their knowledge in the specific topic of the research group
Responsible contact	Daniela, Meilinger; Heinrich, Leonhardt; Hartmann, Harz

Title	Research course: Mechanisms of cell division
Content	During the research course students will address basic question in in the field of cell division. The research course will take 8-weeks with approx. 8 hours per day. In the laboratory we use a broad range of techniques including molecular biology, cell biology, biochemistry, and microscopy. During the course the student will work under supervision and independently after learning the necessary techniques. The student will actively participate in weekly lab meetings and discuss results and questions with other lab members. Based on independent literature researches the student will design a research schedule for the course. All data will be documented, interpreted and discussed by the student in a scientific language and presented in a written report and an oral presentation.
Learning outcomes	After successful completion this module the student will be able to design and perform small scientific projects in the research area of cell division. The students will learn to address a scientific question experimentally and analyze and present the experimental results to a scientific audience.
Responsible contact	Esther, Zanin, Osman, Christof

Title	Research course: Membrane transport in plants
Content	- 8-week research project, approx. 8 hours per day - experience the daily life of scientific research (this includes working in the lab under supervision and also independently, joining lab meetings and discussions) - General methods in our group include heterologous expression of proteins in E. coli and purification with different column based approaches, protein-protein interaction studies with various methods (Co-IPs, Y2H, etc), molecular and biochemical characterization of Arabidopsis mutant lines, organelle isolation and in vitro experiments. - independent literature research - design of a research schedule - document, interpret and discuss the results of their research in scientific language - execution, documentation (lab journal) and analysis of experiments - presentation of the research project both orally and in written form - students eligible need to possess advanced lab skills in basic biochemical and molecular biology methods and not be afraid of working with radioactivity.
Learning outcomes	Students who successfully completed this module are able to… - work on a complex research project related to organellar plant biology - independently design and perform small scientific projects related to the topic of the module on a professional level - discuss the project with colleagues and present their finding in a concise manner - address scientific questions experimentally and analyze experimental results - apply the learning contents and skills from pre-connected modules and deepen their knowledge in the specific topic of the research group
Responsible contact	Jürgen, Soll; Serena, Schwenkert; Bettina, Bölter

Title	Research course: Membrane-biochemical topics

Content	The research course (8-weeks, approx. 8 h/d) students participate in an ongoing research project in molecular microbiology. Specifically, the students investigate the physiological significance, structure, and molecular mechanisms of fuction of integral membrane proteins and associated pathways that are involved in signal trasduction and regulation and/or in solute transport across bacterial membranes (e.g., amino acid uptake into bacteria, drug efflux). Students learn and apply methods related to genetic engeneering of bacteria, cultivation of bacteria, analysis of bacterial population dynmics, solubilization, purification and reconstitution of membrane proteins, fluorescence microscopy and single cell analysis. Students read the relevant literature, develop an experimental strategy to solve a scitific problem and discuss research ideasand strategy with the supervisor. Students perform the experiments indepentently, they document, interpret and discuss the results of their research in scientific language.
Learning outcomes	Students who successfully completed this module are able to work on a complex research project in molecular microbiology. They can address scientific questions experimentally and analyze experimental results related to membrane-bound and metabolic processes in bacteria.
Responsible contact	Heinrich, Jung

Title	Research course: Metabolic acclimation to abiotic stress
Content	In this research course, students will investigate the response of plants to a change in the abiotic environment at the physiological and molecular level. The students will work in a research laboratory and apply selected methods and approaches in the physiological, cellular, molecular, metabolic and biochemical context. Within a research project, quantitative data will be generated and evaluated to explore regulatory mechanisms in abiotic stress responses of plants.
Learning outcomes	In this research course, students should gain advanced knowledge about biological principles of metabolic acclimation to abiotic stress in plants and their investigation at a physiological and molecular level. The students will strengthen and extend their skills for future lab work and learn to document and organize

	their work efficiently. By writing a lab report, they will be able to analyze and evaluate quantitative data and to put their obtained results in a biological context to discuss them critically on a scientific basis.
Responsible contact	Melanie, Paul; Peter, Geigenberger

Title	Research course: Molecular biology and biochemical topics
Content	The research course in the group of Prof. Dr. Kirsten Jung consists of a 8-week research project. In this research course students will get deep insights into molecular microbiology by working on an own research project. Projects will focus on various aspects such as bacterial stress response and translational regulation. Lab meetings with supervisors will ensure a focused development of the research project. A final presentation of the results will support the ability to present the data in a state-of-the-art fashion to a scientific audience.
Learning outcomes	The research course will enable the student to learn modern molecular and spectroscopic techniques and to conduct experiments independently.
Responsible contact	Kirsten, Jung

Title	Research course: Molecular genetics and signal transduction of pathogenic protozoa
Content	Participation in current research, lab work, data interpretation.
Learning outcomes	The practical research course requires independent planning, organization and performance of experiments, including interpretation and documentation of results.
Responsible contact	Michael, Boshart

Title	Research course: Molecular genetics of fungi
Content	Participation in current research, lab work, data interpretation.
Learning outcomes	The practical research course requires independent planning, organization and performance of experiments, including interpretation and documentation of results.
Responsible contact	Andreas, Brachmann

Title	Research course: Molecular Human Genetics / Immunology
Content	The course "Molecular Human Genetics / Immunology" focuses on the interaction of the adaptive immune system with target tissues. The course is embedded in current research projects on the immune response to the Epstein-Barr virus (EBV). By comparing cellular and humoral immune responses against EBV in healthy controls and patients with EBV-associated diseases, we aim to understand why some EBV-infected individuals develop tumors or autoimmune disorders while the vast majority of virus carriers is able to contain the virus as asymptomatic infection. In the course "Molecular Human Genetics / Immunology", genetic as well as environmental cofactors are studied that may increase susceptibility to EBV-associated disorders. In addition, sequence variations in viral strains and their impact on the strain's pathogenicity are investigated. Students will be integrated in ongoing research projects but are trained to design and perform experiments independently. Besides conducting experiments and daily project-related discussions, students are encouraged to present the results of their work in regular lab meetings and participate in institutional progress reports and literature seminars. Additional emphasis is put on documentation, data presentation, and scientific writing.
Learning outcomes	By gaining hands-on experiences in scientific research, students have the possibility to develop practical skills, teamwork competences, scientific reasoning

	capabilities, and to cultivate interest in science and interest in learning science.
Responsible contact	Josef, Mautner

Title	Research course: Molecular plant-microbe interactions
Content	- molecular regulation of the transcription factor CYCLOPS - promotor analysis of the NIN gene, a key factor of root nodule symbiosis. - Synthetic nodules in fragaria - CRISPR/Cas to manipulate/ mutate gene expression/ genes - Nuclear calcium signaling in Oomycete interactions
Learning outcomes	- cell biology - forward and reverse genetics - promotor analysis (computational and with reporter assays) - protein/protein interactions (Co-IP/ Yeast-two hybrid) - protein/ DNA interactions (Yeast-one hybrid) - hairy root transformation
Responsible contact	Martin, Parniske

Title	Research course: Molecular virology
Content	- 8-week research project, approx. 8 hours per day - experience the daily life of scientific research (this includes working in the lab including elaborate cell culture techniques, molecular biology, basic molecular cloning strategies under supervision and also independently, joining lab meetings, journal clubs.) - independent literature research - design of a research schedule - document, interpret and discuss the results of their research in scientific language on a weekly basis - execution, documentation (lab journal) and analysis of experiments

	- presentation of the research project both orally form in front of an informed audience and in written form as structured report
Learning outcomes	A specific focus of the research course is to understand the interaction of virus and the infected host cell at the molecular level. Students who successfully completed this module are able to… - work on a complex research project - independently design and perform small scientific projects related to the topic of the module on a professional level - address scientific questions experimentally and analyze experimental results - apply the learning contents and skills from pre-connected modules and deepen their knowledge in the specific topic of the research group
Responsible contact	Bettina, Kempkes

Title	Research course: mtDNA biology
Content	Students will work on a research project for the duration of 8 weeks under the guidance of the principal investigator, postdocs or graduate students. The project will address unresolved questions regarding the biology of the mitochondrial genome in the model organism S. cerevisiae. The work will include the planning, execution and analysis of experiments. During the 1- week research course, students will join the lab as temporary lab members and take part in all lab meetings and discussions. A workload of appromximately eight hours per day is expected from the students. At the end of the research course, students will present their findings in the lab meeting.
Learning outcomes	Students will experience everyday work in a cell biology labaratory. Students will learn how to address scientific questions experimentally and how to analyse experimental results. Furthermore, students will learn how to present and discuss experimental data in front of experienced cell biologists.
Responsible contact	Christof, Osman

Title	Research course: Peroxisome
Content	Protein quality control of different cellular compartments is an essential feature of living systems. The regulation of cellular compartment-specific protein quality control involves the communication between the respective cellular compartments and the nucleus. The regulation of protein quality control in peroxisomes has not been extensively investigated. In this research course, students will participate in an active research project using a wide range of techniques from Molecular Biology (classical cloning, new cloning techniques (Gibson)), Genetics (RNAi and genetic crosses with loss-of-function mutants), Cell Biology (epifluorescence microscopy, confocal microscopy) and Biochemistry (Western-Blot). The main goal of the project is to get a better understanding of how peroxisomes communicate with the nucleus in the context of peroxisomal quality control.
Learning outcomes	With this course, the one on one situation allows the student to learn more about specific techniques (that could not be done in the context of practical course), to be part of a scientific project and a scientific group, which includes participating in the weekly and monthly group meetings, to gain in independence and potentially to generate his/her own idea.
Responsible contact	Stephane, Rolland

Title	Research course: Plant immunity
Content	Our research course will explore the unique opportunity for interdisciplinary training across the boundaries of genetics, molecular plant biology and microbiology in an important area related to plant health. The course builds on the “Plant Innate Immunity” Lecture, the “Plant Innate Immunity” Practical Course, the “What's new? Plants, microbes & immunity” Seminar, and will be complemented with special interest seminars available from invited speakers. The research course will teach students in practical and theoretical aspects of molecular plant-microbe

	interactions. Students will perform experiments to learn about the plant immune system, how immune signaling is activated to defend infection and how virulent pathogens can circumvent the plant's immune system. Thereby, students will obtain a genetic, molecular and biochemical understanding of immune signaling, such as perception of microbial ligands, activation of immune receptors and substrates, and the trade-off with plant growth. Another important field is the discovery and utilization of microbial extracellular vesicles as immune modulators. The course benefits from integration into current research projects, group meetings, discussing own scientific findings and the relevant original literature. Being directly supervised by experienced researchers, the students will participate in a current research project allowing them to learn the most recent advances in molecular plant-microbe interactions, both in terms of experimental approaches and theoretical concepts. Thereby, students will contribute to current research projects, and have the possibilities to discuss research with experts in the field.
Learning outcomes	At the end of the courses, students will be able to: - -Explain the techniques used in genetics, molecular plant biology and microbiology, both in principle and practice. - -Design and conduct original research to address a problem in plant-bacterial interactions. - -Demonstrate an understanding of original literature. - -Apply problem-solving skills in laboratory experimentation and results conclusions. - Discuss current knowledge and apply critical thinking to plant health and infectious diseases.
Responsible contact	Martin, Parniske; Silke, Robatzek

Title	Research course: Plant metabolism
Content	In this research course, students will investigate various parameters of plant metabolism at different levels of control. Using physiological or genetic manipulations, the response of plants to specific perturbations of the metabolic network will be analyzed. The students will work in a research laboratory and apply selected methods and approaches in the physiological, cellular, molecular, metabolic and

	biochemical context. Within a research project, quantitative data will be generated and evaluated to explore metabolic regulation in the context of plant physiology.
Learning outcomes	Students will expand their knowledge about plant metabolism and methods for its investigation at the molecular level. The students will strengthen and extend their skills for future lab work and learn to document and organize their work efficiently. By writing a lab report, they will be able to analyze and evaluate quantitative data and to put their obtained results in a biological context to discuss them critically on a scientific basis.
Responsible contact	Melanie, Paul; Peter, Geigenberger

Title	Research course: Regulation of cell-cell crosstalk
Content	The course "Regulation of cell-cell crosstalk" focuses on the interaction of the adaptive immune system with target tissues. The course is embedded in current research projects on the immune response to the Epstein-Barr virus (EBV). By comparing cellular and humoral immune responses against EBV in healthy controls and patients with EBV-associated diseases, we aim to understand why some EBV-infected individuals develop tumors or autoimmune disorders while the vast majority of virus carriers is able to contain the virus as asymptomatic infection. In the course "Regulation of cell-cell crosstalk", the focus is on the interaction between virus-specific human T cells and infected target cells, also including viral strategies to evade T-cell recognition and elimination. Students will be integrated in ongoing research projects but are trained to design and perform experiments independently. Besides conducting experiments and daily project-related discussions, students are encouraged to present the results of their work in regular lab meetings and participate in institutional progress reports and literature seminars. Additional emphasis is put on documentation, data presentation, and scientific writing.

Learning outcomes	By gaining hands-on experiences in scientific research, students have the possibility to develop practical skills, teamwork competences, scientific reasoning capabilities, and to cultivate interest in science and interest in learning science.
Responsible contact	Josef, Mautner

Title	Research course: Lab Research course Molecular Microbiology
Content	In the research course (8 weeks, approx. 8 h/d) students participate in an ongoing research project in molecular microbiology. Specifically, the students investigate cell-cell interactions and the bacterial diversity including adaptations of bacteria to ever changing environments. Students learn and apply methods related to the identification of bacteria, genetic engeneering of bacteria, cultivation of bacteria, and metabolic capabilities and features of bacteria. Students read the relevant literature, develop an experimental strategy to solve a scitific problem and discuss research ideasand strategy with the supervisor. Students perform the experiments indepentently, they document, interpret and discuss the results of their research in scientific language.
Learning outcomes	Students who successfully completed this module are able to work on a complex research project in molecular microbiology. They can address scientific questions experimentally and analyze experimental results related to spatiotemporal dynamics of cellular structures and cell division of bacteria.
Responsible contact	W2 Professur Molekulare Mikrobiologie; N.N.

Title	Research course: Lab Research course Cellular Microbiology
Content	In the research course (8 weeks, approx. 8 h/d) students participate in an ongoing research project in bacterial cell biology. Specifically, the students investigate the spatio-temporal dynamics of bacterial structures and the molecular basis of bacterial cell

	division. Students learn and apply methods related to genetic engeneering of bacteria, cultivation of bacteria, fluorescence microscopy and single cell analysis. Students read the relevant literature, develop an experimental strategy to solve a scitific problem and discuss research ideasand strategy with the supervisor. Students perform the experiments indepentently, they document, interpret and discuss the results of their research in scientific language.
Learning outcomes	Students who successfully completed this module are able to work on a complex research project in molecular microbiology. They can address scientific questions experimentally and analyze experimental results related to bacterial diversity and interactions between bacteria.
Responsible contact	W2 Professur Zelluläre Mikrobiologie; N.N.

Title	Research course: Small RNAs and host microbe interactions
Content	- Praktisches Arbeiten im Labor - Wöchentliches Arbeitsseminar - Wöchentliches Literaturseminar - Wöchentliche Diskussion mit dem Supervisor zum Arbeitsthema - Auswertung von eigens erzeugter Daten - Wissenschaftliches Schreiben: Literaturrecherche, Zitieren, schriftlicher Report über eigene praktische Arbeiten im Labor
Learning outcomes	- Praktisches Arbeiten im molekularbiologischen Labor - Evaluation von Daten - Wissenschaftliches Schreiben - Präsentation wissenschaftlicher Daten
Responsible contact	Arne, Weiberg

Title	Research course: Statistical Genetics

Content	Pariticipants carry out a small research project in the statistical genetics group. This may be a comptuter simulation study, a theoretical analysis or a statistical-bioinformatic analysis of a complex dataset.
Learning outcomes	Students gain research experience and are able to plan and conduct an independent research project. Students practice to present and discuss their work. They improve their theoretical knowledge in mathematical modeling in evolutionary biology and/or statistical-bioinformatic methods in statistical genetics.
Responsible contact	Dirk, Metzler

Title	Research course: Visualizing cellular dynamics
Content	- work using a genetically engineered model organism (Dictyostelium discoideum) to visualize cytoskeletal reorganization and cellular dynamics - experience the daily life of scientific research in a small research group (this includes working in the lab under supervision and also independently, joining lab meetings and discussions) - execution, documentation (lab journal) and analysis of experiments - interpretation and discussion of the results within the group - independent literature research - presentation of the research project both orally and in written form
Learning outcomes	Students who successfully completed this module … - obtained insights into high-resolution/superresolution imaging using state-of-the-art microscopes - learned to use Huygens deconvolution and apply Fiji (ImageJ) image analysis tools - learned how to create scientific illustrations - gained insights into work on a complex research project - learned to perform independently small scientific projects related to the topic of the module on a professional level - addressed scientific questions experimentally and are able to analyze the experimental results

	- deepened their knowledge in cytoskeletal research and live-cell imaging
Responsible contact	Annette, Müller-Taubenberger

Title	Research courses in molecular virology
Content	Focus on the biology of human viruses and their involvement in diseases. During the research project students gain hands-on experience in methods used for the research and diagnostics of human viruses . These include but are not limited to - Analysis of viral sequences by PCR-based techniques and bioinformatic tools. - Generation of viral vectors; - Cell culture techniques propagation of viral target cells; - Expression of viral genes; - Their work includes - -Planning and scheduling experiments - Carrying out experiments first under supervision and at a later stage independently; - Consulting the literature to understand the broader context of their project; - Interpretation and critical discussion of experimental results; - Documentation of results; - Generation of a written report of their project in the format of a scientific paper (Sections: Abstract, Introduction, Materials and Methods, Results, Discussion, References and Figures).
Learning outcomes	Students who successfully complete this module will have gained insight into - The scientific background of the subject matter of their project; - Designing and interpreting experiments; - Basics of working on complex research projects; - Methods used to investigate the molecular biology of viruses; - Cell culture methods; - Basics of scientific writing.
Responsible contact	Ruth, Brack-Werner