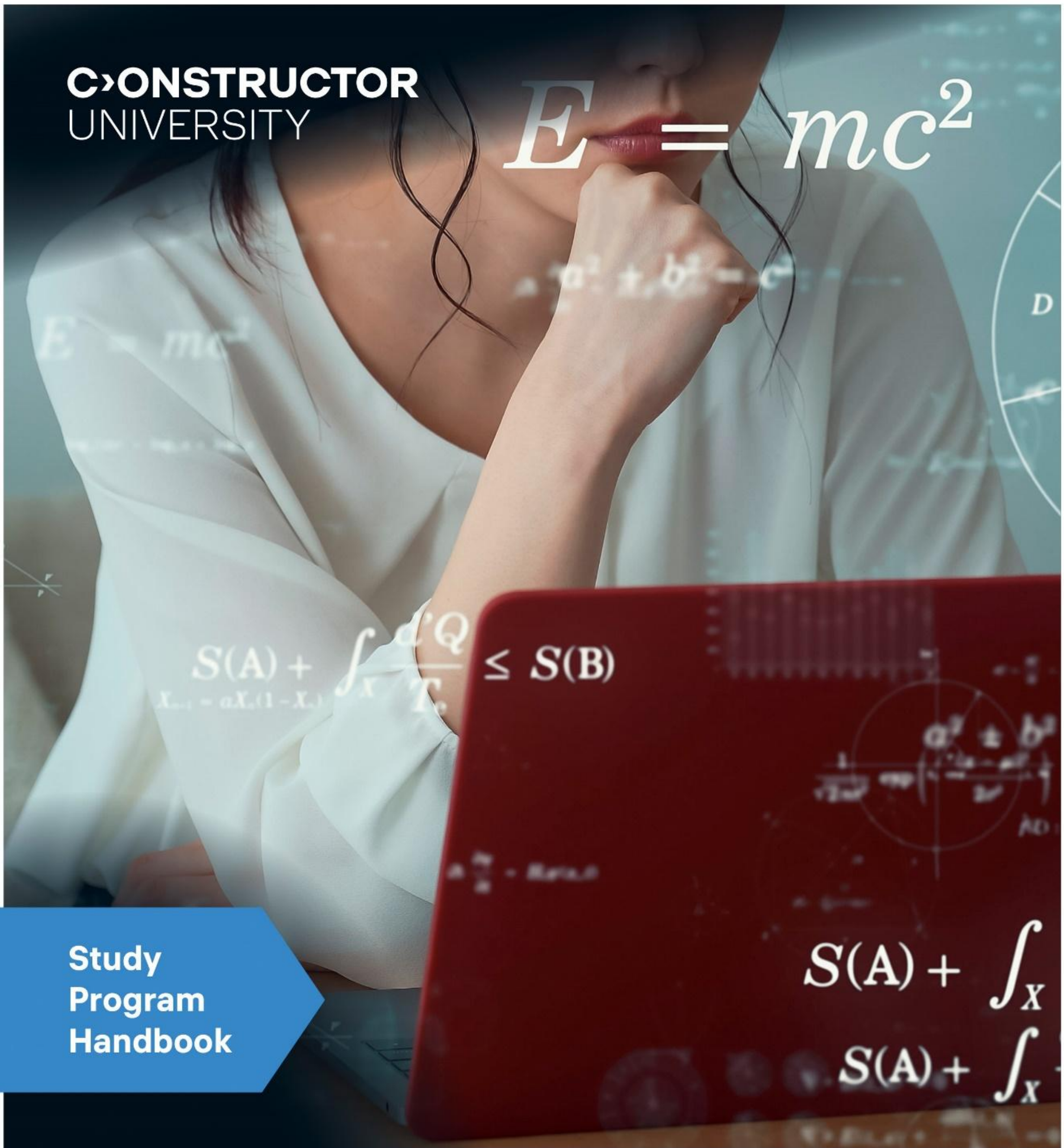

Study Program Handbook

Physics and Data Science

Bachelor of Science

Subject-specific Examination Regulations for Physics and Data Science (Fachspezifische Prüfungsordnung)

The subject-specific examination regulations for Physics and Data Science are defined by this program handbook and are valid only in combination with the General Examination Regulations for Undergraduate degree programs (General Examination Regulations = Rahmenprüfungsordnung). This handbook also contains the program-specific Study and Examination Plan (Chapter 6).

Upon graduation, students in this program will receive a Bachelor of Science (BSc) degree with a scope of 180 ECTS (for specifics see Chapter 4 of this handbook).

Version	Valid as of	Decision	Details
Fall 2023.V1.4		Nov 25, 2025	Editorial update: The module code for Quantum Informatics has been corrected from MCSSE-BA-01 to MCSSE-BT-01
Fall 2023.V1.3		Sep 18, 2023	Editorial changes in the study scheme
Fall 2023.V1.2		Aug 02, 2023	Editorial change of all study schemes
Fall 2023-V1.1		May 26, 2023	Editorial changes in all handbooks
Fall 2023 – V1	Sep 01, 2023	March 1, 2023	Substantial change approved by the Academic Senate
		Jun 26, 2019	Originally approved by Academic Senate

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1 Program Overview

1.1 Concept

1.1.1 The Constructor University Educational Concept

Constructor University aims to educate students for both an academic and a professional career by emphasizing three core objectives: academic excellence, personal development, and employability to succeed in the working world. Constructor University offers an excellent, research driven education experience across disciplines to prepare students for graduate education as well as career success by combining disciplinary depth and interdisciplinary breadth with supplemental skills education and extra-curricular elements. Through a multi-disciplinary, holistic approach and exposure to cutting-edge technologies and challenges, Constructor University develops and enables the academic excellence, intellectual competences, societal engagement, professional and scientific skills of tomorrows leaders for a sustainable and peaceful future.

In this context, it is Constructor University's aim to educate talented young people from all over the world, regardless of nationality, religion, and material circumstances, to become citizens of the world who are able to take responsible roles for the democratic, peaceful, and sustainable development of the societies in which they live. This is achieved through a high-quality teaching as well as manageable study loads and supportive study conditions. Study programs and related study abroad programs convey academic knowledge as well as the ability to interact positively with other individuals and groups in culturally diverse environments. The ability to succeed in the working world is a core objective for all study programs at Constructor University, both in terms of actual disciplinary subject matter and also to the social skills and intercultural competence. Study-program-specific modules and additional specializations provide the necessary depth, interdisciplinary offerings provide breadth while the university-wide general foundation and methods modules, optional German language and Humanities modules, and an extended internship period strengthen the employability of students. The concept of living and learning together on an international campus with many cultural and social activities supplements students' education. In addition, Constructor University offers professional advising and counseling.

Constructor University's educational concept is highly regarded both nationally and internationally. While the university has consistently achieved top marks over the last decade in Germany's most comprehensive and detailed university ranking by the Center for Higher Education (CHE), it has also been listed by the renowned Times Higher Education (THE) magazine as one of the top 300 universities worldwide (ranking group 251-300) in 2019, as well as 2021. Since 2022 Constructor University is considered to be among the top 30 percent out of more than 1600 universities worldwide and is ranked the most international university in Germany. The THE ranking is considered as one of the most widely observed university rankings. It is based on five major indicators: research, teaching, research impact, international orientation, and the volume of research income from industry.

1.1.2 Program Concept

Physics has shaped our view of the universe and the world around us by studying the basic concepts of space, time, and matter. Physics not only lays the foundation for other natural sciences and many engineering disciplines but is also a fundamental part of modern technology such as transistors, lasers, or global positioning systems. Physics is also of fundamental importance for global challenges such as global warming, E-mobility, or renewable energies. Moreover, quantum computing is a rapidly emerging technology that harnesses phenomena of quantum mechanics to tackle problems too complex for classical computers.

At the same time, simulations and experiments in many areas of research and especially in physics generate vast amounts of data. To fully use this data and extract meaningful insights, advanced methods of data science including machine learning are essential. Data Science tools have countless further applications in almost all aspects of daily life.

Physicists describe our world by using only a few basic principles and together with mathematical methods connect and apply these principles. As in any natural science, physicists check their theoretical outcomes by performing appropriate experiments. The ability to analyze and interpret experimental and computational data is largely being enhanced by advanced tools of data science. The qualification aims for a Physics and Data Science bachelor's degree therefore include on one hand a solid knowledge about the basic physical concepts, how they can be used to explain natural phenomena or technical devices and how to design and perform experiments. On the other hand, graduates of the Physics and Data Science BSc program will be able to analyze, evaluate and decipher experimental and computational data to investigate unknown phenomena or to verify new theories. To do so, a Physics and Data Science BSc student is trained in a thorough understanding of mathematical methods, computational and data science tools, and other quantitative problem-solving skills to describe phenomena and complex systems.

The Constructor University Physics and Data Science major is a three-year BSc program. Its physics content is oriented along the guidelines of the Konferenz der Fachbereiche der Physik (KFP) in Germany, the Institute of Physics (Britain) for BSc in Physics, and the topics required for the Graduate Record Examination (GRE) Physics test. The data science component is being developed and taught in close collaboration with the Computer Science faculty at Constructor University. The Physics and Data Science program is frequently optimized and fine-tuned by feedback from students and instructors and developments in research and teaching.

The first year starts with a broad introduction to classical and modern physics as well as mathematics, complemented by a programming lab, an introduction to data structures and algorithms, and a choice of one other subject. The emphasis is on an overview of physical phenomena, their mathematical foundations and basic skills. The second year of study features a thorough and advanced education in the foundations of physics (analytical mechanics, electrodynamics, quantum mechanics, and statistical physics) and scientific data handling (scientific data analysis, machine learning, computational modelling). Lectures and interactive seminars with constant learning feedback by means of weekly homework are complemented by hands-on work in teaching labs. Students are encouraged to join a research group even before their thesis work. Between the fourth and fifth semester, students will take part in an internship in a company or at an academic institution. The third year finally features a selection of specialization courses in physics and data science and guided research leading to the BSc thesis. A Constructor University BSc in Physics and Data Science is an excellent preparation for postgraduate programs and a solid and at the same time flexible foundation for careers in many fields, from research and education to engineering and business. The broad training in analytical skills, technical thinking, data handling and analysis and the appreciation of complexity and subtlety allows data-oriented physicists to also work often with additional qualification in finance and consulting/management. Physicists are the all-rounders among the natural scientists. The Physics and Data Science curriculum at Constructor University is designed to ensure that graduates will be well prepared for postgraduate programs in physics, data science, and related fields at global leading universities.

The scientific knowledge, the international network of Physics alumni, and the problem-solving and social skills acquired during studies of Physics and Data Science at Constructor University guarantee success in our increasingly technology-driven society, as demonstrated by our many very successful graduates.

1.2 Specific Advantages of Physics and Data Science at Constructor University

The institutional framework of the three-year Constructor University Physics and Data Science BSc program is unique in its internationality and research experience. Students gain extra learning and research experience through an internship and by working in research groups of professors for their BSc thesis work or even before. The level of courses is on par with physics programs at leading international universities.

Since students live on our residential campus, they are immersed in a stimulating international and academic community, supporting and enhancing their learning. This provides an ideal preparation for postgraduate studies of physics or data science and related fields at leading international universities.

Our physics graduates are very successful in either being admitted to top postgraduate programs (MSc/PhD) in physics and related fields, directly entering employment, or starting their own businesses. We use feedback from our graduates to continuously improve our study program, and the graduates themselves benefit from our international alumni network.

1.3 Program-Specific Educational Aims

1.3.1 Qualification Aims

Our main objective is to provide a broad and thorough education in physics and data science with some advanced topics and exposure to research. Students learn the foundations and advanced concepts of classical and modern physics together with the required mathematical foundations, programming and computational skills. In lab courses and research projects, they are provided with hands-on training in experimental methods and techniques as well as with advanced data handling and computational approaches. By giving presentations, writing lab reports, small code projects, term papers, and the BSc thesis, they gain familiarity with tools and approaches to access and communicate scientific information. The BSc education in physics and data science at Constructor University is designed to serve as an excellent foundation for graduate programs in physics, data science, and related fields. As such, it contains the core topics of any serious physics program (analytical mechanics, electrodynamics, quantum mechanics, statistical physics, as well as condensed matter physics and specialization topics such as biophysics, computational physics, particles and fields, and electronic devices) and complements that with an equally thorough education in data science (data structures, algorithms, data analysis, machine learning, computing and coding). The ability to analyze complex systems, logical and quantitative thinking, solid mathematical skills, and a broad background in diverse phenomena is an asset for any profession in modern society.

1.3.2 Intended Learning Outcomes

By the end of the program, students will be able to:

1. recall and understand the basic facts, principles, formulas, and experimental evidence from the major fields of physics, namely, classical physics (mechanics, thermodynamics, optics, and electrodynamics), modern physics (including atomic physics, quantum mechanics, relativity, and elementary particle physics), and statistical physics;
2. describe and understand natural and technical phenomena by reducing them to basic physical principles from the various fields of physics;
3. analyze complex systems to extract underlying and organizing principles;
4. use programming skills to build and assess data-based models;
5. apply a variety of mathematical methods and tools especially from analysis and linear algebra to describe physical systems;
6. use numerical and computational methods to describe and analyze physical systems;
7. design and apply data management tools, including the case of large datasets;
8. examine physical problems and apply their mathematical skills and knowledge from different fields in physics to find possible solutions and assess them critically;
9. conceive and apply analogies, approximations, estimates, or extreme cases to test the plausibility of ideas or solution to physical problems;
10. set up and perform experiments, analyze their outcomes with the pertinent precision, and present them properly;
11. proficiently perform advanced statistical data analysis and apply artificial intelligence tools for data processing;
12. work responsibly in a team on a common task, with the necessary preparation, planning, communication, and work organization;
13. use the appropriate language of the scientific community to communicate, discuss, and defend scientific findings and ideas in physics;
14. familiarize themselves with a new field in physics by finding, reviewing, and digesting the relevant scientific information to work independently or as a team member on a physics-related problem or on a scientific research project;
15. apply their knowledge and understanding from their BSc Physics and Data Science education to advance their personal career either by professional employment or by further academic or professional education;
16. take on responsibility for their own personal and professional role in society by critical self-evaluation and self-analysis;
17. adhere to and defend ethical, scientific, and professional standards, but also reflect on and respect different views;
18. act as a scientifically literate citizen to provide sound evidence-based solutions and arguments especially when communicating with specialists or laymen, or when dealing with technology or science issues;
19. appreciate the importance of education, community, and diversity for personal development and a peaceful and sustainable world.

1.4 Career Options and Support

Physicists are the all-rounders among the natural scientists and data scientists are the all-rounders in information technology and the handling of vast amounts of data. About two-thirds work on advancing our scientific knowledge or developing new technologies, products, and processes. Research positions are found in research centers, scientific institutes, and universities. In industry, data-aware physicists and data scientists work in fields like IT, software development, data management, as well as in classical fields for physicists, i.e., electronics, lasers, optics, and semiconductors. An increasing demand for data-aware physicists also comes from the medical technology sector. Another large fraction of physicists or innovative data scientists hold faculty positions at universities and colleges or work in other branches of education.

A Constructor University BSc in Physics and Data Science provides a solid and simultaneously flexible foundation for careers in diverse fields, from basic research (which frequently includes scientific data analysis) to engineering and life sciences, to finance and management. The scientific knowledge, the data handling qualification, the problem-solving skills, and the social skills acquired during studies of physics and data science at Constructor University guarantee success in our increasingly technology-driven society, as demonstrated by our many very successful graduates.

The physics and data science curriculum at Constructor University is designed to ensure that graduates will be well prepared for postgraduate programs in physics, data science and related fields at leading international universities. Physics-related content is oriented along the guidelines of the Konferenz der Fachbereiche der Physik (KFP) in Germany, the Institute of Physics (Britain) for BSc in Physics, and the topics required for the Graduate Record Examination (GRE) physics test.

The broad training in analytical skills, data handling, technical thinking, and the appreciation of complexity and subtlety allows data-aware physicists to work—often with additional qualifications—as management consultants, patent attorneys, market analysts, or risk managers. Many BSc degree recipients go on to graduate in Physics, Data Science and other fields, as careers in research and development usually require a postgraduate degree.

Constructor University Physics BSc graduates have an excellent placement record in top graduate programs, which will improve further by the added data handling skills in the present program. Very helpful for career development is also the opportunity for international network building with Constructor University students coming from more than one hundred different nations. Good communication skills are essential, since many physicists work as part of a team, have contact with clients with non-physics backgrounds, and need to write research papers and proposals. These skills are particularly well developed in the broad and multidisciplinary undergraduate program at Constructor University.

The Career Service Center (CSC) helps students in their career development. It provides students with high-quality training and coaching in CV creation, cover letter formulation, interview preparation, effective presenting, business etiquette, and employer research as well as in many other aspects, thus helping students identify and follow up on rewarding careers after graduating from Constructor University. Furthermore, the Alumni Office helps students establish a long-lasting and global network which is useful when exploring job options in academia, industry, and elsewhere.

1.5 Admission Requirements

Admission to Constructor University is selective and based on a candidate's school and/or university achievements, recommendations, self-presentation, and performance on required standardized tests. Students admitted to Constructor University demonstrate exceptional academic achievements, intellectual creativity, and the desire and motivation to make a difference in the world.

The following documents need to be submitted with the application:

- Recommendation Letter (optional)
- Official or certified copies of high school/university transcripts
- Educational History Form
- Standardized test results (SAT/ACT) if applicable
- Motivation statement
- ZeeMee electronic resume (optional)
- Language proficiency test results (TOEFL Score: 90, IELTS: Level 6.5 or equivalent)

Formal admission requirements are subject to higher education law and are outlined in the Admission and Enrollment Policy of Constructor University.

For more detailed information about the admission visit: https://constructor.university/admission-aid/application-information-undergraduate

1.6 More Information and Contact

For more information on the study program please contact the Study Program Coordinator:

Prof. Dr. Peter Schupp

Professor of Physics

Email: pschupp@constructor.university

| Constructor University - Inspiration is a Place

Prof. Dr. Veit Wagner

Professor of Physics

Email: vwagner@constructor.university

| Constructor University - Inspiration is a Place

or visit our program website:

https://constructor.university/programs/undergraduate-education/physics-and-data-science

For more information on Student Services please visit:

https://constructor.university/student-life/student-services

2 The Curricular Structure

2.1 General

The curricular structure provides multiple elements for enhancing employability, interdisciplinarity, and internationality. The unique CONSTRUCTOR Track, offered across all undergraduate study programs, provides comprehensive tailor-made modules designed to achieve and foster career competency. Additionally, a mandatory internship of at least two months after the second year of study and the possibility to study abroad for one semester give students the opportunity to gain insight into the professional world, apply their intercultural competences and reflect on their roles and ambitions for employment and in a globalized society.

All undergraduate programs at Constructor University are based on a coherently modularized structure, which provides students with an extensive and flexible choice of study plans to meet the educational aims of their major as well as minor study interests and complete their studies within the regular period.

The framework policies and procedures regulating undergraduate study programs at Constructor University can be found on the website (https://constructor.university/student-life/student-services/university-policies).

2.2 The Constructor University 4C Model

Constructor University offers study programs that comply with the regulations of the European Higher Education Area. All study programs are structured according to the European Credit Transfer System (ECTS), which facilitates credit transfer between academic institutions. The three-year undergraduate program involves six semesters of study with a total of 180 ECTS credit points (CP). The undergraduate curricular structure follows an innovative and student-centered modularization scheme - the 4C-Model.It groups the disciplinary content of the study program in three overarching themes, CHOICE-CORE-CAREER according to the year of study, while the university-wide CONSTRUCTOR Track is dedicated to multidisciplinary content, methods as well as intellectual skills and is integrated across all three years of study. The default module size is 5 CP, with smaller 2.5 CP modules being possible as justified exceptions, e.g., if the learning goals are more suitable for 2.5 CP and the overall student workload is balanced.

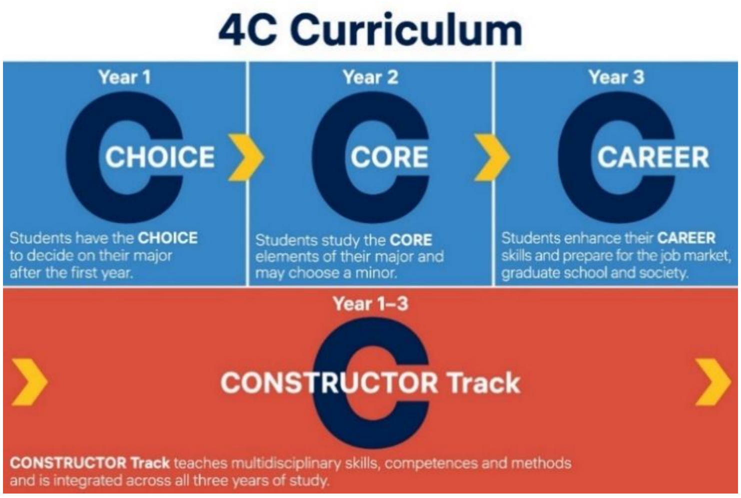

Figure 1: The Constructor University 4C-Model

2.2.1 Year 1 – CHOICE

The first study year is characterized by a university-specific offering of disciplinary education that builds on and expands upon the students' entrance qualifications. Students select introductory modules for a total of 45 CP from the CHOICE area of a variety of study programs, of which 15-45 CP will belong to their intended major. A unique feature of our curricular structure allows students to select their major freely upon entering Constructor University. The team of Academic Advising Services offers curriculum counseling to all Bachelor students independently of their major, while Academic Advisors, in their capacity as contact persons from the faculty, support students in deciding on their major study program..To pursue an MMDA major, the following CHOICE modules (30 CP) need to be taken as mandatory modules during the first year of study:

To pursue an PHDS major, the following CHOICE modules (30 CP) need to be taken as mandatory modules during the first year of study:

- CHOICE Module: Classical Physics (m, 7.5 CP)
- CHOICE Module: Programming in Python and C++ (m, 7.5 CP)
- CHOICE Module: Modern Physics (m, 7.5 CP)
- CHOICE Module: Mathematical Modeling (m, 7.5 CP)

Students can choose between the following two mandatory elective CHOICE modules in the second semester:

- CHOICE Module: Core Algorithms and Data Structures (me, 7.5 CP) or
- CHOICE Module: Algorithms and Data Structures (me, 7.5 CP)

The remaining CHOICE module (7.5 CP) can be selected in the first semester of study according to interest and/or with the aim of allowing a change of major (see 2.2.1.1 below).

Students can still change to another major at the beginning of their second year of studies, provided they have taken the corresponding mandatory CHOICE modules in their first year of studies. All students must participate in an entry advising session with their Academic Advisors to learn about their major change options and consult their Academic Advisor during the first year of studies prior to changing their major.

To allow further major changes after the first semester the students are strongly recommended to register for the CHOICE modules of one of the following study programs:

- Mathematics, Modeling and Data Analytics (MMDA)
  CHOICE Module: Analysis (m, 7.5 CP)
  CHOICE Module: Programming in Python and C++ (m, 7.5 CP)
  CHOICE Module: Linear Algebra (m, 7.5 CP)
  CHOICE Module: Mathematical Modelling (m, 7.5 CP)
  CHOICE Module: Core Algorithms and Data Structures (me, 7.5 CP) or
  CHOICE Module: Algorithms and Data Structures (me, 7.5 CP)

- Sofware, Data and Technology(SDT)
  CHOICE Module: Programming in Python and C++ (m, 7.5 CP)
  CHOICE Module: Analysis (m, 7.5 CP)
  CHOICE Module: Core Algorithms and Data Structures (m, 7.5 CP)

CHOICE Module: Programming in Kotlin (m, 7.5 CP)

- Electrical and Computer Engineering (ECE)
  CHOICE Module: General Electrical Engineering I (m, 7.5 CP)
  CHOICE Module: General Electrical Engineering II (m, 7.5 CP
  CHOICE Module: Classical Physics (m, 7.5 CP)
  CHOICE Module: Introduction to Computer Science (m, 7.5 CP)

- Integrated Social and Cognitive Psychology (ISCP)
  CHOICE Module: Essentials of Cognitive Psychology (m, 7.5 CP)
  CHOICE Module: Essentials of Social Psychology (m, 7.5 CP)

2.2.2 Year 2 – CORE

In their second year, students take a total of 45 CP from a selection of in-depth, discipline-specific CORE modules. Building on the introductory CHOICE modules and applying the methods students have already acquired so far (see 2.3.1), these modules aim to expand the students' critical understanding of the key theories, principles, and methods in their major for the current state of knowledge and best practice.

To pursue Physics and Data Science, the following 45 CP mandatory CORE modules need to be acquired:

- CORE Module: Analytical Mechanics (m, 5 CP)
- CORE Module: Electrodynamics & Relativity (m, 5 CP)
- CORE Module: Quantum Mechanics (m, 5 CP)
- CORE Module: Statistical Physics (m, 5 CP)
- CORE Module: Advanced Physics Lab I (m, 5 CP)
- CORE Module: Advanced Physics Lab II (m, 5 CP)
- CORE Module: Computational Modeling (m, 5 CP)
- CORE Module: Scientific Data Analysis (m, 5 CP)
- CORE Module: Machine Learning (m, 5 CP)

The Physics and Data Science CORE modules contain an advanced discussion of the major fields of physics and data science, as indicated by their titles.

2.2.2.1 Minor Option

The option to pursue a minor in an additional subject is currently not offered because of the double major nature of Physics and Data Science.

2.2.3 Year 3 – CAREER

During their third year, students prepare for and make decisions about their career after graduation. To explore available choices, and to gain professional experience, students take a mandatory summer internship or choose the startup option. The third year of studies allows Physics and Data Science students to take specialization modules in their discipline, but it also focuses on the responsibility of students beyond their discipline (see CONSTRUCTOR Track).

The fifth semester also opens a mobility window for a diverse range of study abroad options. Finally, the sixth semester is dedicated to fostering the students' research experience by involving them in an extended bachelor thesis project.

2.2.3.1 Internship / Start-up and Career Skills Module

As a core element of Constructor University's employability approach, students must engage in a mandatory two-month internship of 15 CP that will usually be completed during the summer between the second and third years of study. This gives students the opportunity to gain first-hand practical experience in a professional environment, apply their knowledge and understanding in a professional context, reflect on the relevance of their major to employment and society, reflect on their own role in employment and society, and find a professional orientation. The internship can also establish valuable contacts for the students' bachelor's thesis project, for the selection of a Master program graduate school or further employment after graduation. This module is complemented by career advising and several career skills workshops throughout all six semesters that prepare students for the transition from student life to professional life. As an alternative to the full-time internship, students interested in setting up their own company can apply for a start-up option to focus on developing their business plans.

For further information, please contact the Student Career Support (https://www.Constructor-university.de/career-services).

2.2.3.2 Specialization Modules

In the third year of studies, students take 15 CP from major-specific or major-related, advanced Specialization Modules to consolidate their knowledge and to be exposed to state-of-the-art research in the areas of their interest. This curricular component is offered as a portfolio of modules, from which students can make selections during their fifth and sixth semester. The default Specialization Module size is 5 CP, with smaller 2.5 CP modules being possible.

To pursue Physics and Data Science as a major, 10 CP of the following major-specific PHYSICS Specialization Modules need to be taken.

- PHYSICS Specialization: Condensed Matter Physics (me, 5 CP)
- PHYSICS Specialization: Particles, Fields and Quanta (me, 5 CP)
- PHYSICS Specialization: Biophysics (me, 2.5 CP)*
- PHYSICS Specialization: Atoms and Molecules (me, 2.5 CP)*
- PHYSICS Specialization: Nanotechnology (me, 2.5 CP)*
- PHYSICS Specialization: Advanced Optics (me, 2.5 CP)*

(*: offered biennially – see Study and Examination Plan.)

and 5 CP of the following major-specific DATA SCIENCE Specializations Modules need to be taken:

- DATA SCIENCE Specialization: Deep Learning (me, 5 CP)
- DATA SCIENCE Specialization: Data Visualization and Image Processing (me, 5 CP)
- DATA SCIENCE Specialization: Stochastic Modeling and Financial Mathematics (me, 5 CP)

A maximum of 5 CP can be taken from major-related modules instead of major-specific Specialization Modules:

- MCSSE: Quantum Informatics (me, 5 CP)
- MMDA Specialization: Foundations of Mathematical Physics (me, 5 CP)
- MMDA Specialization: Topology and Differential Geometry (me, 5 CP)

- ECE CORE: Electronics (me, 5 CP)
- ECE CORE: Information Theory (me, 5 CP)
- CBT CORE: Physical Chemistry (me, 5 CP)

Further specialization modules can be voluntarily taken on top of the 180 CP required for graduation (these will not be graduation-relevant). Please consult a Physics and Data Science SPC for further options.

2.2.3.3 Study Abroad

Students have the opportunity to study abroad for a semester to extend their knowledge and abilities, broaden their horizons and reflect on their values and behavior in a different context as well as on their role in a global society. For a semester abroad (usually the 5th semester), modules related to the major with a workload equivalent to 22.5 CP must be completed. Modules recognized as study abroad CP need to be pre-approved according to Constructor University study abroad procedures. Several exchange programs allow students to directly enroll at prestigious partner institutions worldwide. Constructor University's participation in Erasmus+, the European Union's exchange program, provides an exchange semester at several European universities that include Erasmus study abroad funding.

For further information, please contact the International Programs office (https://constructor.university/student-life/study-abroad/international-office)

Physics and Data Science students that wish to pursue a study abroad in their 5th semester are required to select their modules at the study abroad partners such that they can be used to substitute between 10-15 CP of major-specific Specialization modules and between 5-15 CP of modules equivalent to the non-disciplinary New Skills modules (see CONSTRUCTOR Track). In their 6th semester, according to the study plan, returning study-abroad students complete the Bachelor Thesis/Seminar module (see next section), they take any missing specialization modules to reach the required 15 CP in this area, and they take any missing New Skills modules to reach 15 CP in this area.

2.2.3.4 Bachelor Thesis/Seminar Module

This module is a mandatory graduation requirement for all undergraduate students. It consists of two module components in the major study program guided by a Constructor University faculty member: the Bachelor Thesis (12 CP) and a Seminar (3 CP). The title of the thesis will appear on the students' transcripts.

Within this module, students apply the knowledge, skills, and methods they have acquired in their major discipline to become acquainted with actual research topics, ranging from the identification of suitable (short-term) research projects, preparatory literature searches, the realization of discipline-specific research, and the documentation, discussion, and interpretation of the results.

With their bachelor thesis students demonstrate mastery of the contents and methods of their major-specific research field. Furthermore, students show the ability to analyze and solve a well-defined problem with scientific approaches, a critical reflection of the status quo in scientific literature, and the original development of their own ideas. With the permission of a Constructor University faculty supervisor, the bachelor thesis can also have an interdisciplinary nature. In the seminar, students present and discuss their theses and reflect on their theoretical or experimental approach and conduct. They learn to present their chosen research topics concisely and comprehensively in front of an audience and to explain their methods, solutions, and results to both specialists and non-specialists.

2.2.4 The CONSTRUCTOR Track

The CONSTRUCTOR Track is another important feature of Constructor University's educational model. The Constructor Track runs orthogonal to the disciplinary CHOICE, CORE, and CAREER modules across all study years and is an integral part of all undergraduate study programs. It provides an intellectual tool kit for lifelong learning and encourages the use of diverse methodologies to approach cross-disciplinary problems. The CONSTRUCTOR track contains Methods, New Skills and German Language and Humanities modules.

2.2.4.1 Methods Modules

Methods such as mathematics, statistics, programming, data handling, presentation skills, academic writing, and scientific and experimental skills are offered to all students as part of the Methods area in their curriculum. The modules that are specifically assigned to each study program equip students with transferable academic skills. They convey and practice specific methods that are indispensable for each students' chosen study program. Students are required to take 20 CP in the Methods area. The size of all Methods modules is 5 CP.

To pursue PHDS as a major, the following Methods modules (20 CP) must be taken as mandatory modules:

- Methods Module: Matrix Algebra & Advanced Calculus I (m, 5 CP)
- Methods Module: Matrix Algebra & Advanced Calculus II (m, 5 CP)
- Methods Module: Probability and Random Processes (m, 5 CP)
- Methods Module: Statistics and Data Analytics (m, 5 CP)

2.2.4.2 New Skills Modules

This part of the curriculum constitutes an intellectual and conceptual tool kit that cultivates the capacity for a particular set of intellectual dispositions including curiosity, imagination, critical thought, and transferability. It nurtures a range of individual and societal capacities, such as self-reflection, argumentation and communication. Finally, it introduces students to the normative aspects of inquiry and research, including the norms governing sourcing, sharing, withholding materials and research results as well as others governing the responsibilities of expertise as well as the professional point of view.

All students are required to take the following modules in their second year:

- New Skills Module: Logic (m, 2.5 CP)
- New Skills Module: Causation and Correlation (m, 2.5 CP)

These modules will be offered with two different perspectives of which the students can choose. The module perspectives are independent modules which examine the topic from different point of views. Please see the module description for more details.

In the third year, students take three 5 CP modules that build upon previous modules in the track and are partially constituted by modules that are more closely linked to each student's disciplinary field of study. The following module is mandatory for all students:

- New Skills Module: Argumentation, Data Visualization and Communication (m, 5 CP)

This module will also be offered with two different perspectives of which the students can choose.

In their fifth semester, students may choose between:

- New Skills Module: Linear Model/Matrices (me, 5 CP) and
- New Skills Module: Complex Problem Solving (me, 5 CP).

The sixth semester also contains the choice between two modules, namely:

- New Skills Module: Agency, Leadership and Accountability (me, 5 CP) and
- New Skills Module: Community Impact Project (me, 5 CP).

Students who study abroad during the fifth semester and are not substituting the mandatory "Argumentation, Data Visualization and Communication" module, are required to take this module during their sixth semester. Students who remain on campus are free to take the Argumentation, Data Visualization and Communication module in either the fifth or sixth semester as they prefer.

2.2.4.3 German Language and Humanities Modules

German language abilities foster students' intercultural awareness and enhances their employability in their host country. They are also beneficial for securing mandatory internships (between the 2nd and 3rd year) in German companies and academic institutions. Constructor University supports its students in acquiring basic as well as advanced German skills in the first year of the CONSTRUCTOR Track. Non-native speakers of German are encouraged to take 2 German modules (2.5 CP each) but are not obliged to do so. Native speakers and other students not taking advantage of this offering take alternative modules in Humanities in each of the first two semesters:

- Humanities Module: Introduction to Philosophical Ethics (me, 2.5 CP)
- Humanities Module: Introduction to the Philosophy of Science (me, 2.5 CP)
- Humanities Module: Introduction to Visual Culture (me, 2.5 CP)

3 Physics as a Minor

Physics not only lays the foundation for other natural sciences and many engineering disciplines but is also a fundamental part of modern technology. A physics minor is especially interesting for students who want to gain a solid quantitative foundation of the description of nature starting with the concepts of motion, force and energy, particles, and fields, or want to learn about computational modeling. In a physics minor, these topics are discussed in more depth and breadth than it is possible in disciplines such as chemistry, life science, or earth and environmental science. Engineering-oriented students can learn more about the scientific foundations of their engineering discipline. By choosing a physics minor, math-oriented students learn how mathematical and computational methods can be applied to describe real-world phenomena or to solve technical problems.

3.1 Qualification Aims

The main objective of a physics minor is a broad overview of the different fields in physics in the first year and a focus on some in-depth topics in the second year. Students will learn about the foundations of physics with some advanced concepts of classical and modern physics. In lab courses, they will receive hands-on training in experimental methods and techniques in physics. By writing lab reports, they will gain familiarity with the field-specific language and scientific standards in physics. In the second year, they will focus on more specific topics, use more advanced mathematical and computational tools as well as advanced physical concepts to describe physical phenomena.

3.1.1 Intended Learning Outcomes

With a minor in Physics, students will be able to:

1. recall and understand the basic facts, principles, formulae, and experimental evidence from the major fields of physics, namely, classical physics (mechanics, thermodynamics, optics, and electrodynamics) and modern physics (relativity, quantum mechanics, statistical physics);
2. describe and understand natural and technical phenomena by reducing them to basic physical principles from selected fields of physics;
3. apply basic mathematical methods to describe physical systems;
4. examine physical problems and apply appropriate mathematical methods and physical knowledge to find possible solutions within a specific field of physics;
5. set up and perform basic experiments in physics, analyze their outcomes with pertinent precision and present them properly.

3.2 Module Requirements

A minor in Physics requires 30 CP. The default option to obtain a minor in Physics is marked in the Study and Examination Plan in Chapter 6. It includes the following CHOICE and CORE modules:

- CHOICE Module: Classical Physics (m, 7.5 CP)
- CHOICE Module: Modern Physics (m, 7.5 CP)
- CORE Module: Analytical Mechanics (m, 5 CP)
- CORE Module: Quantum Mechanics (m, 5 CP)
- CORE Module: Computational Modelling (m, 5 CP)

The selection of CHOICE modules is fixed to ensure a solid foundation in physics, but to accommodate different interests, the default CORE modules for a physics minor listed above can be replaced by other advanced physics modules chosen from the following units: Advanced Physics, Advanced Labs, Specialization Physics (see Study and Examination Plan in Chapter 5). Prerequisites must be observed, participation in advanced physics labs is limited and not guaranteed when choosing these modules in a minor. Consultation with the academic advisor and the Physics and Data Science study program chair is required.

3.3 Degree

After successful completion, the minor in Physics will be listed on the final transcript under PROGRAM OF STUDY and BA/BSc – [name of the major] as "(Minor: Physics)."

4 Physics and Data Science Undergraduate Program Regulations

4.1 Scope of these Regulations

The regulations in this handbook are valid for all students who entered the Physics and Data Science undergraduate program at Constructor University in Fall 2023. In the case of a conflict between the regulations in this handbook and the general Policies for Bachelor Studies, the latter applies (see http://www.Constructor-university.de/academic-policies).

In exceptional cases, certain necessary deviations from the regulations of this study handbook might occur during the course of study (e.g., change of the semester sequence, assessment type, or the teaching mode of courses).

In general, Constructor University reserves therefore the right to change or modify the regulations of the program handbook also after its publication at any time and in its sole discretion.

4.2 Degree

Upon successful completion of the study program, students are awarded a Bachelor of Science degree in Physics and Data Science.

4.3 Graduation Requirements

In order to graduate, students need to obtain 180 CP. In addition, the following graduation requirements apply:

Students need to complete all mandatory components of the program as indicated in the Study and Examination Plan in Chapter 6 of this handbook.

5 Schematic Study Plan for Physics and Data Science

Figure 2: schematically shows the sequence and types of modules required for the study program. A more detailed description, including the assessment types, is given in the Study and Examination Plan in the following section.

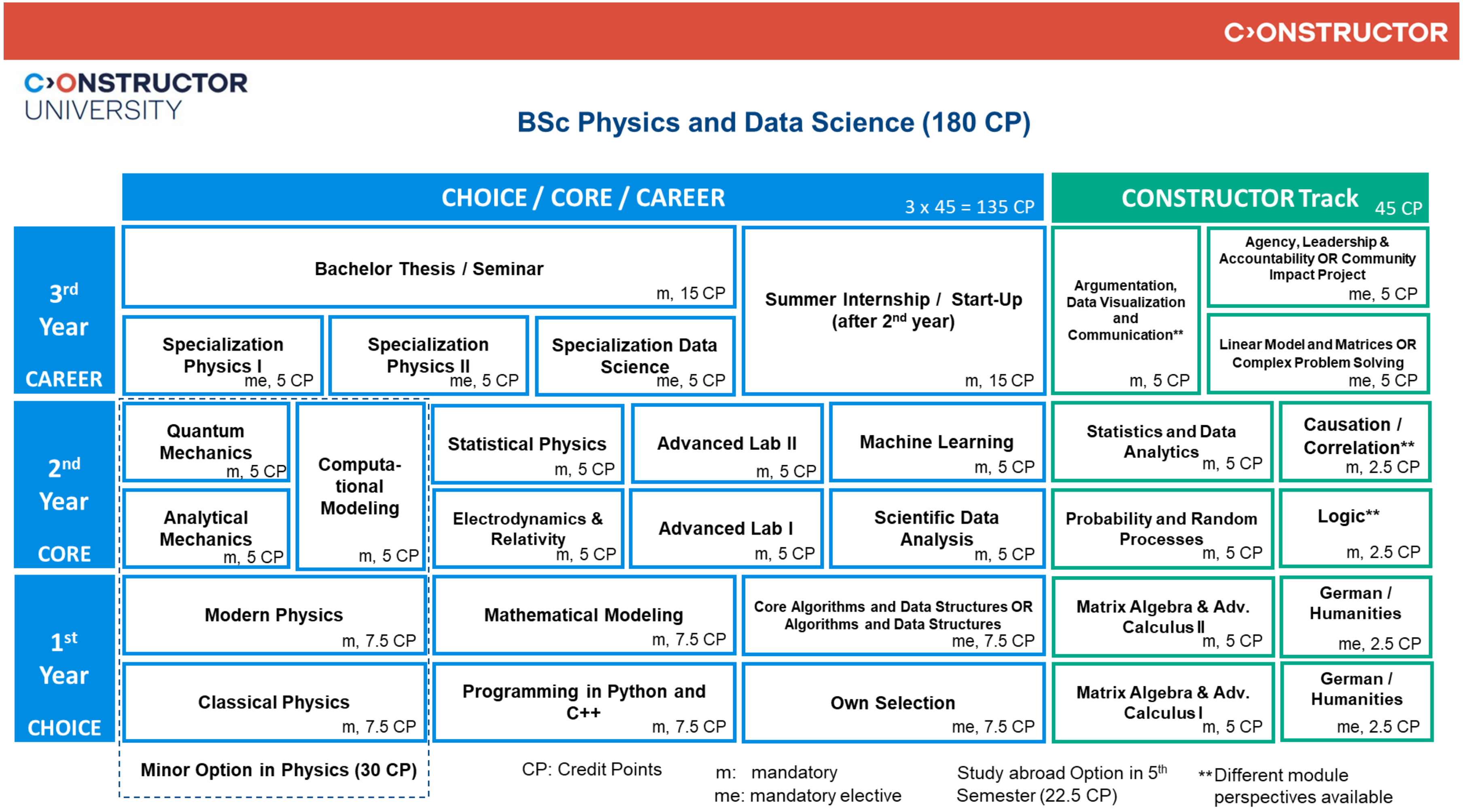

Figure 2: Schematic Plan PHDS

6 Study and Examination Plan

Physics and Data Science BSc

Matriculation Fall 2023

	Program-Specific Modules	**Type**	**Assessment**	**Period**	**Status[1]**	**Sem.**	**CP**
Year 1 - CHOICE							**45**
Take the mandatory CHOICE modules listed below, these are a requirement for the physics and data science program.							
	Unit: Classical and Modern Physics (default minor)						**15**
CH-140	**Module: Classical Physics** (default minor)				**m**	**1**	**7.5**
CH-140-A	Classical Physics	Lecture	Written examination	Examination period			5
CH-140-B	Classical Physics Lab	Lab	Laboratory report	During the semester			2.5
CH-141	**Module: Modern Physics** (default minor)				**m**	**2**	**7.5**
CH-141-A	Modern Physics	Lecture	Written examination	Examination period			5
CH-141-B	Modern Physics Lab	Lab	Laboratory report	During the semester			2.5
	Unit: Mathematics and Modeling						**15**
Take the mandatory CORE modules listed below, these are a requirement for the physics and data science program.							
SDT-101	**Module: Programming in Python and C++**				**m**	**1**	**7.5**
SDT-101 -A	Programming in Python and C++	Lecture	Written examination	Examination period			5
SDT-101 -B	Programming in Python and C++ - Lab	Lab	Practical Assessment	During the semester			2.5
CH-152	**Module: Mathematical Modeling**				**m**	**2**	**7.5**
CH-152-A	Mathematical Modeling	Lecture	Written examination	Examination period			5
CH-152-B	Mathematical Modeling Lab	Lab	Laboratory report	During the semester			2.5
	Unit: Data Science						**15**
	Take one of the two mandatory elective CHOICE modules listed below, these are a requirement for the physics and data science program.						
SDT-102	**Module: Core Algorithms and Data Structures**				**me**	**2**	**7.5**
SDT-102-A	Core Algorithms and Data Structures	Lecture	Written examination	Examination period			5
SDT-102-B	Core Algorithms & Data Structures - Lab	Lab	Practical Assessment	During the semester			2.5
CH-231	**Module: Algorithms and Data Structures**				**me**	**2**	**7.5**
CH-231-A	Algorithms and Data Structures	Lecture	Written examination	During the semester			
*Take **one further CHOICE module** from those offered for other study programs in the first semester.*					**me**	1	7.5
Year 2 - CORE							**45**
	Unit: Advanced Physics						**20**
CO-480	**Module: Analytical Mechanics** (default minor)[2]				**m**	**3**	**5**
CO-480-A	Analytical Mechanics	Lecture	Written examination	Examination period			
CO-481	**Module: Quantum Mechanics** (default minor)[2]				**m**	**4**	**5**
CO-481-A	Quantum Mechanics	Lecture	Written examination	Examination period			
CO-483	**Module: Electrodynamics & Relativity**				**m**	**3**	**5**
CO-483-A	Electrodynamics & Relativity	Lecture	Written examination	Examination period			
CO-484	**Module: Statistical Physics**				**m**	**4**	**5**
CO-484-A	Statistical Physics	Lecture	Written examination	Examination period			
	Unit: Advanced Labs						**10**
CO-486	**Module: Advanced Physics Lab I**		Oral examination	Before examination period	**m**	**3**	**5**
CO-486-A	Advanced Physics Lab I	Lab	Laboratory report	During the semester			
CO-487	**Module: Advanced Physics Lab II**		Oral examination	Before examination period	**m**	**4**	**5**
CO-487-A	Advanced Physics Lab II	Lab	Laboratory report	During the semester			
	Unit: Advanced Data Science						**15**
CO-489	**Module: Scientific Data Analysis**				**m**	**3**	**5**
CO-489-A	Scientific Data Analysis	Lecture	Portfolio	During the semester			
CO-482	**Module: Computational Modelling** (default minor)[2]				**m**	**3/4**	**5**
CO-482-A	Computational Modelling I	Lectures	Project	During the semester			2.5
CO-482-B	Computational Modelling II	Lectures	Project	During the semester			2.5
CO-541	**Module: Machine Learning**				**m**	**4**	**5**
CO-541	Machine Learning	Lecture	Written examination	Examination Period			

	Constructor Track Modules (General Education)	**Type**	**Assessment**	**Period**	**Status[1]**	**Sem.**	**CP**
							15
	Unit: Skills / Methods						**10**
CTMS-MAT-22	**Module: Matrix Algebra & Advanced Calculus I**				**m**	**1**	**5**
CTMS-22	Matrix Algebra & Advanced Calculus I	Lecture	Written examination	Examination period			
CTMS-MAT-23	**Module: Matrix Algebra & Advanced Calculus II**				**m**	**2**	**5**
CTMS-23	Matrix Algebra & Advanced Calculus II	Lecture	Written examination	Examination period			
	Unit: German Language and Humanities (choose one module for each sememster)						**5**
German is default language and open to Non-German speakers (on campus and online).[5]							
CTLA-	**Module: Language 1**				**me**	**1**	**2.5**
CTLA-	Language 1	Seminar	Various	Various			
CTLA-	**Module: Language 2**				**me**	**2**	**2.5**
CTLA-	Language 2	Seminar	Various	Various			
CTHU-HUM-001	**Humanities Module: Introduction into Philosophical Ethics**				**me**	**1**	**2.5**
CTHU-001	Introduction into Philosophical Ethics	Lecture (online)	Written examination	Examination period			
CTHU-HUM-002	**Humanities Module: Introduction to the Philosophy of Science**				**me**	**2**	**2.5**
CTHU-002	Introduction to the Philosophy of Science	Lecture (online)	Written examination	Examination period			
CTHU-HUM-003	**Humanities Module: Introduction to Visual Culture**				**me**	**2**	**2.5**
CTHU-003	Introduction to Visual Culture	Lecture (online)	Written examination	Examination period			
							15
	Unit: Methods					3+4	**10**
CTMS-MAT-12	**Module: Probability and Random Processes**				**m**	**3**	**5**
CTMS-12	Probability and Random Processes	Lecture	Written examination	Examination period			
CTMS-MET-21	**Module: Statistics and Data Analytics**				**m**	**4**	**5**
CTMS-21	Statistics and Data Analytics	Lecture	Written examination	Examination period			
	Unit: New Skills						**5**
Choose one of the two modules							
CTNS-NSK- 01	**Module: Logic (perspective I)**				**me**	**3**	**2.5**
CTNS-01	Logic (perspective I)	Lecture (online)	Written Examination	Examination period			
CTNS-NSK-02	**Module: Logic (perspective II)**				**me**	**3**	**2.5**
CTNS-02	Logic (perspective II)	Lecture (online)	Written Examination	Examination period			
Choose one of the two modules							
CTNS-NSK-03	**Module: Correlation and Causation (perspective I)**				**me**	**4**	**2.5**
CTNS-03	Correlation and Causation (perspective I)	Lecture (online)	Written Examination	Examination period			
CTNS-NSK-04	**Module: Correlation and Causation (perspective II)**				**me**	**4**	**2.5**
CTNS-04	Correlation and Causation (perspective II)	Lecture (online)	Written Examination	Examination period			

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CA-INT-900	**Module: Internship / Startup and Career Skills**				**m**	**4/5**	**15**
CA-INT-900-0	Internship / Startup and Career Skills	Intersnhip	Report/Business Plan	During the 5th semester			
CA-PHDS-800	**Module: Thesis / Seminar Physics and Data Science**				**m**	**6**	**15**
CA-PHDS-800-T	Thesis Physics and Data Science	Project	Thesis and Presentation	15th of May			12
CA-PHDS-800-S	Seminar Physics and Data Science	Seminar		During the semester			3
	Unit: Specialization Physics (*Take a total of 10 CP of specialization modules*) [4]						**10**
CA-S-PHDS-801	**Module: Condensed Matter Physics**				**me**	**5**	**5**
CA-PHDS-801-A	Condensed Matter and Devices	Lecture	Written examination	Examination period			
CA-S-PHDS-802	**Module: Particles, Fields and Quanta**				**me**	**6**	**5**
CA-PHDS-802-A	Elementary Particles and Fields	Lecture	Project with presentation	During the semester			2.5
CA-PHDS-802-B	Advanced Quantum Physics	Lecture					2.5
CA-S-PHDS-804/806	**Module: Biophysics (A) / Nanotechnology (B)**				**me**	**6**	**2.5**
CA-PHDS-804/806-A	Biophysics / Nanotechnology	Lecture	Project with presentation	During the semester			
CA-PHDS-805/807	**Module: Atoms & Molecules (A) / Advanced Optics (B)**				**me**	**6**	**2.5**
CA-PHDS-805/807-A	Atoms & Molecules / Advanced Optics	Lecture	Project with presentation / examination	During the semester / Examination period			
	Unit: Specialization Data Science (*Take a total of 5 CP of specialization modules*)						**5**
MCSSE-AI-01	**Module: Deep Learning**				**me**	**5**	**5**
MCSSE-AI-01	Deep Learning	Lecture	Written examination	Examination period			
MDE-CO-05	**Module: Data Visualization and Image Processing**				**me**	**5**	**5**
MDE-CO-05	Data Visualization and Image Processing	Lecture	Written examination	Examination period			
CA-S-MMDA-803	**Module: Stochastic Moedling and Financial Mathematics**				**me**		**5**
CA-MMDA-803	Stochastic Modeling and Financial Mathematics	Lecture	Portfolio	During the semester			
	Unit: Other major-specific Specialization modules (Can replace max 5 CP of specialization modules described above)						**5**
MCSSE-BT-01	**Module: Quantum Informatics**				**me**	**6**	**5**
MCSSE-BT-01-A	Quantum Informatics	Lecture	Written examination	Examination period			2.5
MCSSE-BT-01-B	Quantum Informatics Lab	Lab	Portfolio	During the semester			2.5
CA-S-MATH-806	**Module: Foundations of Mathematical Physics**				**me**	**5**	**5**
CA-S-MATH-806	Foundations of Mathematical Physics	Lecture	Written examination	Examination period			
CA-S-MMDA-801	**Module: Topology and Differential Geometry**				**me**		**5**
CA-MMDA-801	Topology and Differential Geometry	Lecture	Written examination	Examination period			
CO-526	**Module: Electronics**				**me**	**5**	**5**
CO-526-A	Electronics	Lecture	Written examination	Examination period			2.5
CO-526-B	Electronics Lab	Lab	Laboratory report	During the semester			2.5
CO-525	**Module: Information Theory**				**me**	**6**	**5**
CO-525-A	Information Theory	Lecture	Written examination	Examination period			
CO-440	**Module: Physical Chemistry**				**me**	**5/6**	**5**
CO-440-A	Physical Chemistry	Lecture	Written examination	Examination period			

	Unit: New Skills						**10**
Choose one of the two modules							
CTNS-NSK-05	**Module: Linear Model and Matrices**				**me**	**5**	**5**
CTNS-05	Linear Model and Matrices	Lecture (online)	Written examination	Examination period			
CTNS-NSK-06	**Module: Complex Problem Solving**				**me**	**5**	**5**
CTNS-06	Complex Problem Solving	Lecture (online)	Written examination	Examination period			
Choose one of the two modules							
CTNS-NSK-07	**Module: Argumentation, Data Visualization and Communication**				**me**	**5/6**	**5**
CTNS-07	Argumentation, Data Visualization and Communication (perspective I)	Lecture (online)	Written examination	Examination period		5	
CTNS-NSK-08	**Module: Argumentation, Data Visualization and Communication**				**me**	**5/6**	**5**
CTNS-08	Argumentation, Data Visualization and Communication (perspective II)	Lecture (online)	Written examination	Examination period		**6**	
Choose one of the two modules							
CTNS-NSK-09	**Module: Agency, Accountability & Leadership**				**me**	**6**	**5**
CTNS-09	Agency, Accountability & Leadership	Lecture (online)	Written examination	Examination period			
CTNS-CIP-10	**Module: Community Impact Project**				**me**	**5/6**	**5**
CTNS-10	Community Impact Project	Project	Project	Examination period			

Total CP 180

[1] Status (m = mandatory, me = mandatory elective). [2]Alternative module choices for a minor in physics are possible (see physics study program handbook).
[3] For a full listing of all CHOICE / CORE / CAREER / CONSTRUCTOR Track modules please consult the CampusNet online catalogue and /or the study program handbooks.
[4] Specialization modules indicated with (A) or (B) are offered biennally; the letter A refers to odd-numbered calendar years, the letter B refers to even-numbered calendar years.
[5] German native speakers will have alternatives to the language courses (in the field of Humanities).

Figure 2: Study and Examination Plan

7 Physics Modules

7.1 Classical Physics

Module Name	Module Code	Level (type)	CP
Classical Physics	CH-140	Year 1 (CHOICE)	7.5

Module Components

Number	Name	Type	CP
CH-140-A	Classical Physics	Lecture	5
CH-140-B	Classical Physics Lab	Lab	2.5

Module Coordinator	Program Affiliation	Mandatory Status
Prof. Dr. Jürgen Fritz	• Physics and Data Science (PHDS)	Mandatory for ECE, PHDS, RIS, and minor in Physics Mandatory elective for MMDA

Entry Requirements

Pre-requisites	Co-requisites	Knowledge, Abilities, or Skills	Frequency	Forms of Learning and Teaching
☒ None	☒ None	• High school physics • High school math	Annually (Fall)	• Lecture (35 hours) • Lab (25.5 hours) • Homework (42 hours) • Private study (85 hours)
			Duration 1 semester	**Workload** 187.5 hours

Recommendations for Preparation

A revision of high school math (especially calculus, analytic geometry, and vector algebra) and high school physics (basics of motion, forces, and energy) is recommended. The level and content follow standard textbooks for calculus-based first-year university physics such as Young & Freedman: University Physics, Halliday & Resnick & Walker: Fundamentals of Physics, or Tipler & Mosca: Physics.

Content and Educational Aims

A. This module introduces students to basic physical principles, facts, and experimental evidence in the fields of classical mechanics, thermodynamics, and optics. It lays the foundations for more advanced physics modules and for other science and engineering disciplines. It is intended for students who already have reasonably solid knowledge of basic physics and mathematics at the high school level.

B. Emphasis is placed on general physical principles and general mathematical concepts for a thorough understanding of physical phenomena. Calculus and vector analysis will be used to develop a scientifically sound description of physical phenomena. An optional tutorial is offered to discuss homework or topics of interest in more detail.

C. Topics covered in the module include an introduction to mechanics using calculus, vectors, and coordinate systems; concepts of force and energy, momentum and rotational motion, and gravitation and oscillations; and concepts of thermodynamics such as temperature, heat, ideal gas, and kinetic gas theory up to heat engines and entropy. The module content concludes with an introduction to classical optics including refraction and reflection, lenses and optical instruments, waves, interference, and diffraction.

D. The lectures are complemented by hands-on work in a teaching lab where students apply their theoretical knowledge by performing experiments as well as related data analysis and result presentation. The default lab of this module is the Classical Physics Lab offering experiments in mechanics, thermodynamics, and optics. For students majoring in RIS a Technical Mechanics Lab is offered with a focus on technical mechanics experiments.

Intended Learning Outcomes

By the end of the module, students will be able to

1. recall basic facts and experimental evidence in classical mechanics, thermodynamics, and optics;
2. understand the basic concepts of motion, force, energy, oscillations, heat, and light and apply them to physical phenomena;
3. describe and understand natural and technical phenomena in mechanics, thermodynamics, and optics by reducing them to their basic physical principles;
4. apply basic calculus and vector analysis to describe physical systems;
5. examine basic physical problems, find possible solutions, and assess them critically;
6. set up experiments, analyze their outcomes by using error analysis, and present them properly;
7. record experimental data using basic experimental techniques and data acquisition tools;
8. use the appropriate format and language to describe and communicate the outcomes of experiments and the solutions to theoretical problems.

Indicative Literature

H. Young & R. Freedman: University physics, with modern physics. Upper Saddle River: Prentice Hall.

D. Halliday, R. Resnick, J. Walker: Fundamentals of physics, extended version. Hoboken: John Wiley & Sons Inc.P. Tipler & G. Mosca: Physics for scientists and engineers. New York: WH Freeman.

Usability and Relationship to other Modules

Examination Type: Module Component Examinations

Module Component 1: Lecture

Assessment Type: Written examination (Lecture) — Duration: 120 min, Weight: 67%

Scope: Intended learning outcomes of the lecture (1-5).

Module Component 2: Lab (Classical Physics Lab/ Classical Mechanics Lab)

Assessment Type: Lab Reports (Lab) — Length: 8-12 pages, Weight: 33%

Scope: Intended learning outcomes of the lab (1, 6-8).

A bonus achievement for the lecture module component is offered.

Completion: To pass this module, both module component examinations must be passed with at least 45%.

7.2 Modern Physics

Module Name		Module Code	Level (type)	CP
Modern Physics		CH-141	Year 1 (CHOICE)	7.5
Module Components				
Number	Name		Type	CP
CH-141-A	Modern Physics Lecture		Lecture	5
CH-141-B	Modern Physics Lab		Lab	2.5

Module Coordinator	Program Affiliation	Mandatory Status
Prof. Dr. Veit Wagner, Prof. Dr. Arnulf Materny	• Physics and Data Science (PHDS)	Mandatory for PHDS and minor in Physics

Entry Requirements			Frequency	Forms of Learning and Teaching
Pre-requisites	Co-requisites	Knowledge, Abilities, or Skills	Annually (Spring)	• Lecture (35 hours) • Lab (25.5 hours) • Homework problem (42 hours) • Private study (85 hours)
☒ Classical Physics	☒ None	• High school physics • High school math	**Duration** 1 semester	**Workload** 187.5 hours

Recommendations for Preparation

A revision of high school math (especially calculus, analytic geometry, and vector algebra) and high school physics (basics of forces, fields, energy, and atomic physics) is recommended. The level and content follow standard textbooks for calculus-based first-year university physics such as Young & Freedman: University Physics; Halliday & Resnick & Walker: Fundamentals of Physics; or Tipler & Mosca: Physics.

Content and Educational Aims

Modern technology and the understanding of natural systems are heavily based on electromagnetic phenomena and the physics of the 20th century. This module introduces students to basic physical principles, facts, and experimental evidence from electromagnetism and modern physics. It lays foundations for the more advanced physics modules and for other science and engineering disciplines. It is intended for students who already have reasonably solid knowledge of basic physics and mathematics at the high school level.

Emphasis is placed on general physical principles and general mathematical concepts for a thorough understanding of physical phenomena. Lectures are complemented by hands-on work in a teaching lab where students apply their theoretical knowledge by performing experiments as well as related data analysis and presentation. Data acquisition as well as evaluation involve classical as well as computer-based techniques. Calculus and vector analysis are used to develop a scientifically sound description of physical phenomena. An optional tutorial is offered to discuss homework or topics of interest in more detail.

The electromagnetism part of the module introduces basic electric and magnetic phenomena using the concepts of force, fields, and potentials. This is followed by a discussion of dielectrics and magnetism in matter, electric currents, induction, and Maxwell equations. The modern physics part starts with a short introduction to special relativity. The focus lies on concepts of quantum physics and their use to describe the properties and interactions of particles. This includes a discussion of the particle nature of light and the wave-like nature of particles, Schrödinger's equation, the energy levels of atoms, spin, the basics of molecules and solids, semiconductors and devices, nuclear physics, elementary particles and the standard model of particle physics, and cosmology. The purpose of this module is an overview of important physical concepts. It will prepare students for the in-depth treatment in the second-year courses.

Intended Learning Outcomes

By the end of the module, students will be able to

1. recall the basic facts and experimental evidence in electromagnetism and modern physics;
2. understand the basic concepts of fields, potential, current, elementary particles and their interactions, and the duality of particles and waves, and apply them to physical phenomena;
3. describe and understand natural and technical phenomena in electromagnetism and modern physics by reducing them to their basic physical principles;
4. apply calculus and vector analysis to describe physical systems;
5. examine basic physical problems, find possible solutions, and assess them critically;
6. set up experiments, analyze their outcomes by using error analysis, and present them properly;
7. record experimental data using computer-assisted techniques and data acquisition tools;
8. use statistical methods for data evaluation;
9. use the appropriate format and language to describe and communicate the outcomes of experiments and the solutions to theoretical problems.

Indicative Literature

H. Young & R. Freedman: University physics, with modern physics. Upper Saddle River: Prentice Hall.

D. Halliday, R. Resnick, J. Walker: Fundamentals of physics, extended version. Hoboken: John Wiley & Sons Inc.

P. Tipler & G. Mosca: Physics for scientists and engineers. New York: WH Freeman.

Usability and Relationship to other Modules

Examination Type: Module Component Examinations

Module Component 1: Lecture

Assessment Type: Written examination (Lecture), Duration: 120 min
Weight: 67%

Scope: Intended learning outcomes of the lecture (1-5, 9).

A bonus achievement for the lecture module component is offered.

Module Component 2: Lab

Assessment Type: Lab Reports (Lab), Length: 8-12 pages
Weight: 33%

Scope: Intended learning outcomes of the lab (1, 6-9).

Completion: To pass this module, both module component examinations must be passed with at least 45%.

7.3 Mathematical Modeling

Module Name Mathematical Modeling			Module Code CH-152	Level (type) Year 1 (CHOICE)	CP 7.5
Module Components					
Number	Name			Type	CP
CH-152-A	Mathematical Modeling			Lecture	5
CH-152-B	Mathematical Modeling Lab			Lab	2.5
Module Coordinator Prof. Dr. Sören Petrat and Dr. Ivan Ovsyannikov	**Program Affiliation** • Mathematics, Modeling, and Data Analytics (MMDA)			**Mandatory Status** Mandatory for MMDA, PHDS, Minor in Mathematics	
Entry Requirements Pre-requisites ☒ Matrix Algebra & Advanced Calculus I	Co-requisites ☒ none	Knowledge, Abilities, or Skills • Good command of Calculus and basic Linear algebra	**Frequency** Annually (Spring)	**Forms of Learning and Teaching** Lectures (35 hours) Tutorials (17.5 hours) Private Study (135 hours)	
			Duration 1 semester	**Workload** 187.5 hours	
Recommendations for Preparation • Recap basic Calculus and Linear Algebra knowledge					

Content and Educational Aims

The idea of this module is to introduce and teach mathematical methods starting with concrete scientific problems (mostly but not exclusively taken from physics). This module thus provides a first introduction to mathematical modeling, with an emphasis of the modeling of phenomena in physics, but also in other fields such as biology, economy, engineering, environmental sciences, finance, and industry. In modeling, we face two difficulties: Firstly, we have to find a good mathematical representation of the problem at hand, and secondly, we need to solve this problem either exactly, or with approximate analytical or numerical techniques. This class focuses mostly on deterministic problems and discusses stochastic problems only briefly. The main mathematical techniques come from Analysis/Calculus, Linear Algebra, Differential Equations, and Probability. In the Mathematical Modeling Lab, the students work independently and in groups to find formulations of modeling problems and their solutions.

The following topics will be covered:

- Population Dynamics
- Fluid Mechanics
- Systems of Linear Equations
- Electrical Networks
- Linear Programming
- The Ideal Gas
- First and Second Laws of Thermodynamics
- Harmonic Oscillator
- ODEs and Phase Space
- Stability of Linear Systems
- Electromagnetism and Wave Equation
- Brownian Motion
- Monte-Carlo Method

The following mathematical skills will be covered and developed:

- derivatives and integration in one variable
- derivatives and integration in many variables
- integral theorems: Gauß and Stokes
- extreme value problems
- Taylor series
- Fourier series
- ODEs
- elementary introduction to PDEs
- elementary probability and stochastic processes

Intended Learning Outcomes

Upon completion of this module, students will be able to

1. formulate mathematical models of problems from the sciences
2. describe solution methods to modeling problems
3. explain the usage of analysis and linear algebra techniques in modeling
4. recognize different solution methods for modeling problems
5. illustrate the use of ODEs and PDEs to describe phenomena in physics
6. solve simple stochastic modeling problems

Indicative Literature

- Eck, Garcke, Knaber – Mathematical Modeling

Usability and Relationship to other Modules

- This module is part of the core education in MMDA and PHDS MMDA and PHDS.
- It is also valuable for students in Computer Science, RIS, and ECE, either as part of a minor in Mathematics, or as an elective module.

Examination Type: Module Component Examination

Module Component 1: Mathematical Modeling
Assessment Type: Written examination Duration: 120 min
Weight: 67%
Scope: All intended learning outcomes of this module

Module Component 2: Mathematical Modeling Lab
Assessment Type: Practical assessment (Homework assignments)
Weight: 33%
Scope: All intended learning outcomes of this module

Completion: To pass this module, the examination of each module component has to be passed with at least 45%

7.4 Programming in Python and C++

Module Name		Module Code	Level (type)	CP
Programming in Python and C++		SDT-101	Year 1 (CHOICE)	7.5
Module Components				
Number	Name		Type	CP
SDT-101 -A	Programming in Python and C++		Lectures	5
SDT-101-B	Programming in Python and C++ - Lab		Lab	2.5
Module Coordinator Prof. Dr. Aleksander Omelchenko	**Program Affiliation** • Software, Data and Technology(SDT)		**Mandatory Status** Mandatory for SDT, Minor in SDT, PHDS, and MMDA Mandatory elective for ECE	
Entry Requirements Pre-requisites ☒ none	Co-requisites ☒ none	Knowledge, Abilities, or Skills ☒ none	**Frequency** Annually (Fall)	**Forms of Learning and Teaching** Lectures (35 hours) Tutorials (17.5 hours) Independent study (115 hours) Exam preparation (20 hours)
			Duration 1 semester	**Workload** 187.5 hours

Recommendations for Preparation

Set up a suitable programming environment.

Content and Educational Aims

This course provides a solid foundation in imperative programming concepts and techniques, with a focus on Python and C++ programming languages. This course enables students to write programs in Python that solve problems and perform various operations using functions, data structures, and control structures, provides a basic introduction to the C++ programming language and its standard library, with a focus on data structures and algorithms, develops students' problem-solving and algorithmic thinking skills through hands-on programming exercises and projects, fosters students' ability to design, write, and test programs that are robust, maintainable, and scalable, encourages students to pursue further studies and practice in the field of programming and data science.

Content:

- Introduction to Imperative Programming: Overview of basic concepts of imperative programming languages, including variables, assignments, loops, function calls, data structures, and more.
- Python Programming: Writing interactive programs in Python, working with user input, and testing and debugging code.
- Object-Oriented Programming in Python: Overview of basic object-oriented programming concepts, such as objects, classes, information hiding, inheritance, and function and operator overloading.
- File Input/Output in Python: Retrieving and processing data from/to files, and generating data using Python.
- Scientific Computing with Python: Using NumPy arrays for vectorized code and SciPy for special functions and black-boxed algorithms (root solvers, quadrature, ODE solvers, and fast Fourier transform).
- Visualization in Python: Visualizing data using Matplotlib.
- Introduction to C++ Programming: Writing basic programs in C++ using standard library functions.

- Pointers in C++: Using pointers to create dynamically allocated data structures, such as linked lists, and understanding the relationship between pointers and arrays.
- Standard Library Data Types in C++: Overview of C++ standard library data types, including vector, string, list, map, set, and sort.
- Risks and Limitations of C/C++: Understanding the risks of C/C++ programming, including implicit type conversions, lack of bounds checking, and manual memory ownership management.

Intended Learning Outcomes

Upon completion of this module, students will be able to

1. explain basic concepts of imperative programming languages such as variables, assignments, loops, function calls, data structures, etc.;
2. work with user input from the keyboard, write interactive Python programs;
3. write, test, and debug programs;
4. illustrate basic object-oriented programming concepts such as objects, classes, information hiding and inheritance;
5. give original examples of function and operator overloading;
6. retrieve data and process and generate data from/to files;
7. write vectorized code using NumPy arrays
8. use SciPy for special functions and black-boxed algorithms (root solvers, quadrature, ODE solvers, and fast Fourier transform)
9. visualize data in appropriate ways using Matplotlib
10. write basic programs in the programming languages C/C++ using standard library functions
11. demonstrate how to use pointers to create dynamically allocated data structures such as linked lists;
12. explain the relationship between pointers and arrays;
13. use C++ standard library data types (vector, string, list, map, set, sort);
14. describe C/C++ risks (implicit type conversions, lack of bounds checking, manual memory ownership management)

Indicative Literature

Mark Lutz: "Learning Python", 5th edition, O'Reilly Media, 2013.

Lillian Pierson: "Data Science from Scratch: First Principles with Python", 2nd edition, O'Reilly Media, 2019.

Mark Summerfield: "Programming in Python 3: A Complete Introduction to the Python Language", 2nd edition, Addison-Wesley Professional, 2009.

David J. Pine: “Introduction to Python for Science and Engineering”, CRC Press, 2019.

John V. Guttag: "Introduction to Computation and Programming Using Python", 2nd edition, MIT Press, 2013.

Bjarne Stroustrup: "Programming -- Principles and Practice Using C++", Second edition, Addison-Wesley Professional, 2014.

Stanley Lippman: "C++ Primer (5th Edition)", 2012

Scott Meyers: "Effective Modern C++", O'Reilly Media, 2014.

H. M. Deitel and P. J. Deitel: "C++ How to Program", 10th edition, Pearson, 2015.

John Zelle: "Python Programming: An Introduction to Computer Science", 3rd edition, Franklin, Beedle & Associates, Inc., 2016.

Usability and Relationship to other Modules

Examination Type: Module Component Examination

Component 1: Lecture

Assessment type: Written examination Duration: 120 min

Weight: 67%

Scope: All theoretical intended learning outcomes of the module

Component 2: Lab

Assessment type: Practical assessment

Weight: 33%

Scope: All practical intended learning outcomes of the module

Completion: To pass this module, the examination of each module component has to be passed with at least 45%

7.5 Core Algorithms & Data Structures

Module Name		**Module Code**	**Level (type)**	**CP**
Core Algorithms and Data Structures		SDT-102	Year 1 (CHOICE)	7.5
Module Components				
Number	Name		Type	CP
SDT-102-A	Core Algorithms and Data Structures		Lecture	5
SDT-102-B	Core Algorithms and Data Structures - Lab		Lab	2.5
Module Coordinator Dr. Kinga Lipskoch	**Program Affiliation** ● Software, Data and Technology(SDT)		**Mandatory Status** Mandatory for SDT and Minor in Software Development Mandatory elective for PHDS and MMDA	
Entry Requirements Pre-requisites ☒ Programming in Python and C++ OR Programming in C/C++	Co-requisites ☒ none	Knowledge, Abilities, or Skills	**Frequency** Annually (Spring)	**Forms of Learning and Teaching** Lecture (35 hours) Tutorial (17.5 hours) Independent study (115 hours) Exam preparation (20 hours)
			Duration 1 semester	**Workload** 187.5 hours

Recommendations for Preparation

Students should refresh their knowledge of the C, C++ and Python programming language and be able to solve simple programming problems in C, C++ and Python. Students are expected to have a working programming environment.

Content and Educational Aims

Algorithms and data structures are the foundation of computer science and are crucial for the design and implementation of efficient software programs. In this course, students will learn about fundamental algorithms for solving problems and about data structures for storing, accessing, and modifying data in an efficient manner. They will also learn techniques for analyzing the computational and memory complexities of algorithms and data structures. These concepts and techniques form the basis for almost all computer programs and are essential for success in the fields of data science and software development.

Content:

- Introduction (asymptotic analysis of algorithms, analysis of recurrence relations, sums and integrals, time complexity, non-asymptotic optimizations, cache)
- Basic data structures (array, list, stack, queue, vector, hash tables, binary heap, heapsort, etc.)
- Sorting algorithms and heaps (quadratic sorting, stable sorting, mergesort, etc.)
- Graphs: depth-first search (DFS) and breadth-first search (BFS) algorithms.
- Graphs: matchings, colorings, flows, cuts.
- Graphs: shortest paths
- Introduction to Complexity Theory, Probabilistic Algorithms

- Numerical and Algebraic Algorithms

Intended Learning Outcomes

Upon completion of this module, students will be able to

1. Analyze the time and space complexity of algorithms and optimize them using asymptotic analysis and non-asymptotic techniques such as cache optimization.
2. Implement and evaluate various data structures including arrays, lists, stacks, queues, vectors, hash tables, binary heaps, and heapsort.
3. Compare and contrast different sorting algorithms, including quadratic sorting, stable sorting, and mergesort, and understand the trade-offs involved in their use.
4. Implement depth-first search (DFS) and breadth-first search (BFS) algorithms and understand their applications in graph theory.
5. Analyze matchings, colorings, flows, and cuts in graphs, and understand the algorithms and mathematical foundations used to solve these problems.
6. Implement shortest path algorithms in graphs and understand their applications in network design and routing.
7. Understand the fundamental concepts of complexity theory and probabilistic algorithms, and apply them in solving computational problems.
8. Analyze and implement numerical and algebraic algorithms and understand their applications in a variety of fields.
9. Develop the ability to analyze, design, and implement algorithms for solving real-world problems and understand the trade-offs involved in their use.

Indicative Literature

Thomas H. Cormen, Charles E. Leiserson, Ronald L. Rivest, and Clifford Stein: Introduction to Algorithms, 3rd edition, MIT Press, 2009.

Robert Sedgewick and Kevin Wayne: Algorithms, 4th edition, Addison-Wesley, 2011.

Steven Skiena: The Algorithm Design Manual, 2nd edition, Springer, 2008.

Michael T. Goodrich, Roberto Tamassia, and Michael H. Goldwasser: Data Structures and Algorithms in Python, John Wiley & Sons, 2013.

Jon Kleinberg and Éva Tardos: Algorithm Design, 1st edition, Pearson, 2005.

David E. Goldberg: Genetic Algorithms in Search, Optimization, and Machine Learning, Addison-Wesley, 1989.

Donald E. Knuth: The Art of Computer Programming: Fundamental Algorithms, volume 1, 3rd edition, Addison Wesley Longman Publishing, 1997.

Usability and Relationship to other Modules

- This course will provide students with a solid foundation for understanding how to design and analyze algorithms for solving problems, as well as data structures for efficiently storing and manipulating data.

Examination Type: Module Component Examination

Component 1: Lecture

Assessment type: Written examination — Duration: 120 min

Weight: 67%

Scope: All theoretical intended learning outcomes of the module

Component 2: Lab

Assessment type: Practical assessment — Weight: 33%

Scope: All practical intended learning outcomes of the module

Completion: To pass this module, the examination of each module component has to be passed with at least 45%

7.6 Algorithms and Data Structures

Module Name			Module Code	Level (type)	CP
Module Name Algorithms and Data Structures			**Module Code** CH-231	**Level (type)** Year 1 (CHOICE)	**CP** 7.5
Module Components					
Number	Name			Type	CP
CH-231-A	Algorithms and Data Structures			Lecture	7.5
Module Coordinator Dr. Kinga Lipskoch	**Program Affiliation** • Computer Science (CS)			**Mandatory Status** Mandatory for CS, minor in CS, RIS, ACS, Mandatory elective for PHDS, MMDA	
Entry Requirements Pre-requisites ☒ Programming in C and C++ or Programming in Python and C++	Co-requisites ☒ None	Knowledge, Abilities, or Skills	**Frequency** Annually (Spring)	**Forms of Learning and Teaching** • Class attendance (52.5 hours) • Independent study (115 hours) • Exam preparation (20 hours)	
			Duration 1 semester	**Workload** 187.5 hours	

Recommendations for Preparation

Students should refresh their knowledge of the C and C++ programming language and be able to solve simple programming problems in C and C++. Students are expected to have a working programming environment.

Content and Educational Aims

Algorithms and data structures are the core of computer science. An algorithm is an effective description for calculations using a finite list of instructions that can be executed by a computer. A data structure is a concept for organizing data in a computer such that data can be used efficiently. This introductory module allows students to learn about fundamental algorithms for solving problems efficiently. It introduces basic algorithmic concepts; fundamental data structures for efficiently storing, accessing, and modifying data; and techniques that can be used for the analysis of algorithms and data structures with respect to their computational and memory complexities. The presented concepts and techniques form the basis of almost all computer programs.

Intended Learning Outcomes

By the end of this module, students will be able to

1. explain asymptotic (time and memory) complexities and respective notations;
2. able to prove asymptotic complexities of algorithms;
3. illustrate basic data structures such as arrays, lists, queues, stacks, trees, and hash tables;
4. describe algorithmic design concepts and apply them to new problems;
5. explain basic algorithms (sorting, searching, graph algorithms, computational geometry) and their complexities;
6. summarize and apply C++ templates and generic data structures provided by the standard C++ template library.

Indicative Literature

Thomas H. Cormen, Charles E. Leiserson, Ronald L. Rivest, and Clifford Stein: Introduction to Algorithms, 3rd edition, MIT Press, 2009.

Donald E. Knuth: The Art of Computer Programming: Fundamental Algorithms, volume 1, 3rd edition, Addison Wesley Longman Publishing, 1997.

Usability and Relationship to other Modules

Familiarity with basic algorithms and data structures is fundamental for almost all advanced modules in computer science. This module additionally introduces advanced concepts of the C++ programming language that are needed in advanced programming-oriented modules in the 2nd and 3rd years of the CS and RIS programs.

Examination Type: Module Examination

Assessment Type: Written examination Duration: 120 min
Weight: 100%

Scope: All intended learning outcomes of the module

Completion: To pass this module, the examination has to be passed with at least 45%

7.7 Analytical Mechanics

Module Name			Module Code	Level (type)	CP
Analytical Mechanics			CO-480	Year 2 (CORE)	5
Module Components					
Number	Name			Type	CP
CO-480-A	Analytical Mechanics			Lecture	5
Module Coordinator Prof. Dr. Peter Schupp	**Program Affiliation** • Physics and Data Science			**Mandatory Status** Mandatory for PHDS, minor in Physics Mandatory elective MMDA	
Entry Requirements Pre-requisites ☒ Classical Physics or: Mathematical Modeling	Co-requisites ☒ None	Knowledge, Abilities, or Skills • Mathematics at the level of the Mathematical Modeling module	**Frequency** Annually (Fall)	**Forms of Learning and Teaching** • Lecture (35 hours) • Homework exercises (55 hours) • Private study (35 hours)	
			Duration 1 semester	**Workload** 125 hours	

Recommendations for Preparation

Review classical mechanics, calculus and linear algebra at the level of the first-year courses.

Content and Educational Aims

Mechanics provides the foundation for all other fields of physics. The analytical techniques developed in mechanics have applications in many other sciences, engineering, mathematics and even economics. This module provides an intensive calculus-based introduction to analytical mechanics including aspects of special relativity. Topics include Newton’s laws, the kinematics and dynamics of systems of particles, planetary motion, rigid body mechanics, Lagrangian mechanics, variational techniques, symmetries and conservation laws, optimization with constraints and Lagrange multipliers, Hamiltonian mechanics, canonical transformations, Hamilton-Jacobi theory, Liouville theorem, small oscillations, and relativistic mechanics. Additional topics may include continuum mechanics and an outlook to general relativity. The course is part of the core physics education and builds on the foundation of the Classical Physics and Mathematical Modeling modules. The course is, however, also accessible and of interest to students without this prerequisite, but with a sufficiently strong background in mathematics. Essential practical experience in analyzing physical phenomena, formulating mathematical models and solving physics problems will be supported by homework exercises in close coordination with the lectures. The aim of the module is an introduction to the core topics of physics at a level that prepares students for BSc thesis research. At the same time, students’ mathematical repertoires and problem-solving skills are developed. The module also serves as a foundation for specialization subject courses

Intended Learning Outcomes

By the end of the module, students will be able to

1. understand the classical foundations of physics;
2. solve mechanics problems of practical relevance using advanced mathematical techniques;
3. analyze mechanical systems using Newton's laws and re-formulate them in terms of Lagrangian and Hamiltonian mechanics;
4. formulate physical laws using variational methods and derive the equations of the motion of physical systems;
5. model and analyze systems beyond mechanics using methods and techniques of analytical mechanics;
6. derive the equivalence of energy and matter in the framework of the special theory of relativity;
7. understand Lorentz transformations and apply them;
8. communicate in scientific language using advanced field-specific technical terms.

Indicative Literature

D. Morin (2008). Introduction to Classical Mechanics: With Problems and Solutions. Cambridge: Cambridge University Press;

D. Tong. Lectures on Classical Dynamics. http://www.damtp.cam.ac.uk/user/tong/dynamics.html

and/or:

L. D. Landau, E. M. Lifshitz (1976). Mechanics. Vol. 1, 3rd ed, (chapters on Lagrangian and Hamiltonian mechanics). Oxford: Butterworth-Heinemann

Usability and Relationship to other Modules

- One of three default second year CORE modules for a minor in Physics
- Prerequisite for second year CORE module "Statistical Physics" and specialization module "Particles, Fields and Quanta"
- Co-requisite for second year CORE module "Advanced Physics Lab 1"

Examination Type: Module Examination

Assessment Type: Written examination

Duration: 120 min
Weight: 100%

Scope: All intended learning outcomes of the module

Bonus achievement: Additional bonus homework as a voluntary task can improve the grade but is not required to reach the best grade in the module (1.0).

Completion: To pass this module, the examination has to be passed with at least 45%

7.8 Quantum Mechanics

Module Name Quantum Mechanics			Module Code CO-481	Level (type) Year 2 (CORE)	CP 5
Module Components					
Number	Name			Type	CP
CO-481-A	Quantum Mechanics			Lecture	5
Module Coordinator Prof. Dr. Peter Schupp	**Program Affiliation** • Physics and Data Science			**Mandatory Status** Mandatory for PHDS, minor in Physics Mandatory elective MMDA	
Entry Requirements Pre-requisites ☒ Modern Physics or Mathematical Modeling	Co-requisites ☒ None	Knowledge, Abilities, or Skills • Mathematics at the level of the Mathematical Modeling module	**Frequency** Annually (Spring)	**Forms of Learning and Teaching** • Lectures (35 hours) • Homework exercises (55 hours) • Private study (35 hours)	
			Duration 1 semester	**Workload** 125 hours	
Recommendations for Preparations Review Hamiltonian mechanics.					

Content and Educational Aims

At a fundamental microscopic level, our world is governed by quantum phenomena that frequently defy attempts of a common-sense understanding based on our everyday experience of the macroscopic world. Yet modern technology would not be possible without quantum physics. This module provides an intensive introduction to quantum mechanics. We shall emphasize conceptual as well as quantitative aspects of the theory. Topics include: Foundations and postulates of quantum mechanics; Schrödinger Equation; one-dimensional problems (potential barriers and tunneling); operators, matrices, states (Dirac notation, representations); uncertainty relations; harmonic oscillator, coherent states; angular momentum and spin; EPR paradox and Bell inequalities; central potential (hydrogen atom, multi-electron atoms); perturbation theory; mixed states, entanglement, measurement; aspects of quantum information theory and quantum computing. The course is part of the core physics education, and it is also of interest for students of other natural sciences and mathematics (MMDA). Essential practical experience in analyzing physical phenomena, formulating mathematical models and solving physics problems will be supported by homework exercises in close coordination with the lectures. The aim of the module is an introduction to core topics of physics at a level that prepares for actual research. At the same time, the mathematical repertoire and problem-solving skills are developed. The module also serves as a foundation for physics specialization subjects.

Intended Learning Outcomes

By the end of this module, students will be able to

1. describe particle-wave complementarity in quantum mechanics;
2. present the theoretical foundations of quantum mechanics;

3. solve quantum mechanics problems of practical relevance using advanced mathematical techniques;
4. determine the energy levels of quantum systems using algebraic and analytical methods;
5. communicate in scientific language using advanced field-specific technical terms.

Indicative Literature

L.I. Schiff (1968). Quantum Mechanics 3Rev Ed edition. New York: McGraw-Hill.

D. Tong. Lectures on Quantum Mechanics. http://www.damtp.cam.ac.uk/user/tong/quantum.html

and/or

D.J. Griffiths (2004). Introduction to Quantum Mechanics. Upper Saddle River: Prentice Hall International.

Usability and Relationship to other Modules

Examination Type: Module Examination

Assessment Type: Written examination

Duration: 120 min
Weight: 100%

Scope: All intended learning outcomes of the module.

Bonus achievement: Additional bonus homework as a voluntary task can improve the grade but is not required to reach the best grade in the module (1.0).

Completion: To pass this module, the examination has to be passed with at least 45%

7.9 Computational Modeling

Module Name			Module Code	Level (type)	CP
Computational Modeling			CO-482	Year 2 (CORE)	5

Module Components

Number	Name	Type	CP
CO-482-A	Computational Modeling I	Lecture	2.5
CO-482-B	Computational Modeling II	Lecture	2.5

Module Coordinator	Program Affiliation	Mandatory Status
Prof. Dr. Ulrich Kleinekathöfer	• Physics and Data Science (PHDS)	Mandatory for PHDS, minor in Physics and MMDA

Entry Requirements			Frequency	Forms of Learning and Teaching
Pre-requisites ☒ Mathematical Modeling	Co-requisites ☒ None	Knowledge, Abilities, or Skills • Basics of scientific programming preferably in Python	Annually (Fall and Spring)	• Lecture (35 hours) • Private study (35 hours) • Exercises and project (55 hours)
			Duration 2 semesters	**Workload** 125 hours

Recommendations for Preparation

Review the basics of scientific programming in Python as well as the methods from Mathematical Modeling.

Content and Educational Aims

In this Computational Modeling module, several practical numerical solutions for typical problems in mathematics, physics and the natural sciences in general will be discussed. While, for example, the very nature of physics is the expression of relationships between physical quantities in mathematical terms, an analytical solution of the resulting equations is often not available. Instead, numerical solutions based on computer programs are required to obtain useful results for real-life problems. In the module, several numerical techniques are introduced, such as solving ordinary differential equations, partial differential equations, quadrature, random number generation, and Monte Carlo integration. These important tools in numerical simulations will be applied to a selection of problems including the classical dynamics of particles, chaos theory, electrostatics including the Poisson equation, cellular automata including traffic simulations, random walks, the solution of the time-dependent Schrödinger equation, and so forth. The module includes numerous examples and exercises for programming codes.

Intended Learning Outcomes

By the end of the module, students will be able to

1. explain the basic strategies to simulate mathematical and physical systems;
2. apply computer simulations to describe and analyze general problems in physics, mathematics and related sciences;
3. design computer programs for specific problems and validate them;
4. utilize basic numerical schemes such as iterative approaches;
5. communicate in scientific language using advanced field-specific technical terms.

Indicative Literature

H. Gould, J. Tobochnik, W. Christian (2006). Introduction to Computer Simulation Methods. London: Pearson Education.

And/or:

R. H. Landau, M. J. Paez, C. C. Bordeianu. Computational Physics: Problem Solving with Computers. Weinheim: Wiley-VCH.

Usability and Relationship to other Modules

- This module is part of the core education in MMDA and PHDS.
- Computational Modeling I focuses on examples relevant for the Analytical Mechanics and Electrodynamics & Relativity modules, while Computational Modeling II focuses on examples relevant for the Statistical Physics and Quantum Mechanics modules.
- One of three default second year CORE modules for a minor in Physics

Examination Type: Module Examination

Assessment Type: Project

Duration: 25 hours
Weight: 100%

Scope: All intended learning outcomes of the module

Completion: To pass this module, the examination has to be passed with at least 45%

7.10 Electrodynamics & Relativity

Module Name		Module Code	Level (type)	CP
Electrodynamics & Relativity		CO-483	Year 2 (CORE)	5
Module Components				
Number	Name		Type	CP
CO-483-A	Electrodynamics & Relativity		Lecture	5
Module Coordinator Prof. Dr. Ulrich Kleinekathöfer, Prof. Dr. Veit Wagner	**Program Affiliation** • Physics and Data Science		**Mandatory Status** Mandatory for PHDS	

Entry Requirements			**Frequency**	**Forms of Learning and Teaching**
Pre-requisites	Co-requisites	Knowledge, Abilities, or Skills	Annually (Fall)	• Lectures (35 hours) • Homework exercises (55 hours) • Private study (35 hours)
☒ Modern Physics or Mathematical Modeling	☒ None	• Mathematical methods at the level of the Matrix Algebra and Advanced Calculus II module • Electromagnetism at the level of the first-year physics modules	**Duration** 1 semester	**Workload** 125 hours

Recommendations for Preparations

Review the Matrix Algebra and Advanced Calculus I&II module topics and electromagnetism at the level of the first-year courses.

Content and Educational Aims

Electrodynamics is the prototype theory for all fundamental forces of nature. It plays a profound role in modern communication, computing, and control systems, as well as energy production, transport, storage, and use. This module provides an intensive calculus-based introduction to electrodynamics with a special emphasis on its connections to the theory of special relativity. Topics include electromagnetic fields, Maxwell's equations, electrostatics, magnetostatics, fields in matter, the covariant formulation of electrodynamics and special relativity, electromagnetic radiation, and optics. The course is part of the core physics education and builds in an essential way on the foundation of the first-year Modern Physics and Matrix Algebra and Advanced Calculus modules. The module is however also accessible and of interest to students without this prerequisite, but with a sufficiently strong background in mathematics. Essential practical experience in analyzing physical phenomena, formulating mathematical models, and solving physics problems will be supported by homework exercises in close coordination with the lectures. The aim of the module is an introduction to the core topics of physics at a level that prepares students for BSc thesis research. At the same time, students' pertinent mathematical repertoires and problem-solving skills are developed. The module also serves as a foundation for physics specialization subjects.

Intended Learning Outcomes

By the end of this module, students will be able to

1. describe Maxwell's equations and present practical applications of electrodynamics;
2. apply advanced mathematical techniques to solve electrodynamics problems;
3. analyze electrodynamic phenomena and relate them to the underlying fundamental physical laws including special relativity;
4. communicate in scientific language using advanced field-specific technical terms.

Indicative Literature

D. Tong (2015). Electromagnetism, https://www.damtp.cam.ac.uk/user/tong/em.html
and/or

D.J. Griffiths (2017). Introduction to Electrodynamics, 4th edition. Cambridge: Cambridge University Press.

Usability and Relationship to other Modules

- Possible elective for a Physics minor

Examination Type: Module Examination

Assessment Type: Written examination Duration: 120 min
Weight: 100%

Scope: All intended learning outcomes of the module.

Bonus achievement: Additional bonus homework as a voluntary task can improve the grade but is not required to reach the best grade in the module (1.0).

Completion: To pass this module, the examination has to be passed with at least 45%

7.11 Statistical Physics

Module Name Statistical Physics		Module Code CO-484	Level (type) Year 2 (CORE)	CP 5
Module Components				
Number	Name		Type	CP
CO-484-A	Statistical Physics		Lecture	5
Module Coordinator Prof. Dr. Stefan Kettemann, Prof. Dr. Veit Wagner	**Program Affiliation** • Physics and Data Science		**Mandatory Status** Mandatory for PHDS	
Entry Requirements Pre-requisites ☒ Analytical Mechanics	Co-requisites ☒ None	Knowledge, Abilities, or Skills • First-year mathematics	**Frequency** Annually (Spring)	**Forms of Learning and Teaching** • Lectures (35 hours) • Homework exercises (55 hours) • Private study (35 hours)
			Duration 1 semester	**Workload** 125 hours
Recommendations for Preparations Review thermal physics and calculus at the level of the first-year courses.				

Content and Educational Aims

Statistical physics describes macroscopic properties of matter by a statistical treatment of their microscopic constituents and finds applications in fields ranging from biophysics to condensed matter and high energy physics. This course deals with an intensive introduction to statistical physics and its applications in condensed matter theory. The course starts with an introduction to the mathematical concepts followed by a brief review of the thermodynamic concepts and quantities. Topics in statistical physics include the statistical basis of thermodynamics, micro-canonical, canonical and grand-canonical ensembles, macroscopic variables, physical applications including an introduction to quantum statistical physics such as Fermi and Bose quantum gases, and related physical phenomena. Based on the multi-particle wave functions of fermions, applications in condensed matter physics are discussed, including Bloch wave functions and the density of states. Essential practical experience in analyzing physical phenomena, formulating mathematical models and solving physics problems will be supported by homework exercises in close coordination with the lectures. The aim of the module is an introduction to the core topics of physics at a level that prepares for BSc thesis research. At the same time, students' pertinent mathematical repertoires and problem-solving skills are developed. The module also serves as a foundation for physics specialization subjects.

Intended Learning Outcomes

By the end of this module, students will be able to

1. understand the theoretical foundations and practical applications of statistical physics;
2. solve thermodynamics and statistical physics problems of practical relevance using advanced mathematical techniques;
3. analyze properties of gases and condensed matter in terms of microscopic and statistical models;
4. communicate in scientific language using advanced field-specific technical terms.

Indicative Literature

S. Salinas (2001). Introduction to Statistical Physics. New York: Springer.

and/or

H. Gould & J. Tobochnik (2010). Thermal and Statistical Physics. Princeton: Princeton University Press.

Usability and Relationship to other Modules

- Possible elective for a Physics minor

Examination Type: Module Examination

Assessment Type: Written examination

Duration: 120 min
Weight: 100%

Scope: All intended learning outcomes of the module.

Bonus achievement: Additional bonus homework as a voluntary task can improve the grade but is not required to reach the best grade in the module (1.0).

Completion: To pass this module, the examination has to be passed with at least 45%

7.12 Advanced Physics Lab I

Module Name			Module Code	Level (type)	CP
Advanced Physics Lab I			CO-486	Year 2 (CORE)	5
Module Components					
Number	Name			Type	CP
CO-486-A	Advanced Physics Lab I			Lab	5
Module Coordinator Prof. Dr. Veit Wagner, Prof. Dr. Arnulf Materny	**Program Affiliation** • Physics and Data Science			**Mandatory Status** Mandatory for PHDS	
Entry Requirements			**Frequency**	**Forms of Learning and Teaching**	
Pre-requisites	Co-requisites	Knowledge, Abilities, or Skills	Annually (Fall)	• Lab (51 hours) • Private study (74 hours)	
☒ Modern Physics	☒ Analytical Mechanics, Electrodynamics & Relativity	• First-year mathematics	**Duration**	**Workload**	
			1 semester	125 hours	

Recommendations for Preparation

Students should recap their first year physics, especially from the lab courses including error analysis.

Content and Educational Aims

Physics is an experimental science. Any hypotheses or theories must be tested, verified, or falsified by experiments. Therefore, designing and performing experiments, analyzing, and presenting experimental results is a fundamental part of any physics education. In this module, students advance their knowledge in performing experiments as it was introduced in the first-year modules; students work more independently on experiments and write a scientific lab report. They will conduct hands-on experiments on advanced topics in advanced mechanics and electrodynamics requiring an advanced theoretical and mathematical description of phenomena. Scheduled experiments are: Dynamics of rotational motion, Ultrasonic waves, Thermal and electrical conductivity, Hall Effect, Polarization of visible light, Scanning electron microscopy (SEM).
By working in teams of two, they will set up experiments, record data, analyze it using the appropriate software and error analysis, and present it in a written report. They will finally describe and explain their work in an oral exam.

Intended Learning Outcomes

By the end of the module, students will be able to

1. prepare for the conducting of experiments and use experimental equipment for a specific physical problem;
2. set up, perform, and evaluate experiments to investigate typical phenomena in mechanics and electrodynamics;
3. use experimental techniques and data acquisition tools to record experimental data;
4. analyze the outcomes of experiments by mathematical and computational methods, and use error analysis to assess the accuracy and reproducibility of their results;
5. use the appropriate format and language to summarize and describe an experiment, and communicate its outcome in a scientific report;

6. organize their work and work responsibly in a team to fulfill the given task;
7. orally describe and answer basic questions related to the background, the experimental method, and outcome of the experiment.

Indicative Literature

A lab manual will be provided.

Usability and Relationship to other Modules

- Possible elective for a Physics minor

Examination Type: Module Examination

Assessment 1: Lab reports (written and oral components)
Written reports — Length: 10-15 pages
Weight: 70%

Scope: Intended learning outcomes (1-6).

Assessment 2: Oral examination — Duration: 30 min
Weight: 30%

Scope: Intended learning outcomes (4,7).

Completion: To pass this module, the examination of each assessment has to be passed with at least 45%.

7.13 Advanced Physics Lab II

Module Name			Module Code	Level (type)	CP
Advanced Physics Lab II			CO-487	Year 2 (CORE)	5
Module Components					
Number	Name			Type	CP
CO-487-A	Advanced Physics Lab II			Lab	5
Module Coordinator Prof. Dr. Arnulf Materny, Prof. Dr. Veit Wagner	**Program Affiliation** • Physics and Data Science			**Mandatory Status** Mandatory for PHDS	
Entry Requirements Pre-requisites ☒ Modern Physics	Co-requisites ☒ Quantum mechanics, Statistical Physics	Knowledge, Abilities, or Skills • First-year mathematics	**Frequency** Annually (Spring)	**Forms of Learning and Teaching** • Lab (51 hours) • Private study (74 hours)	
			Duration 1 semester	**Workload** 125 hours	

Recommendations for Preparation

Students should recap their first year physics, especially from the lab courses including error analysis.

Content and Educational Aims

Physics is an experimental science. Any hypotheses or theories must be tested, verified, or falsified by experiments. Therefore, designing and performing experiments, analyzing, and presenting experimental results is a fundamental part of any physics education. In this module, students advance their knowledge in performing experiments as introduced in the first-year modules; students work more independently on experiments and write a scientific lab report. They will conduct hands-on experiments on advanced topics in quantum mechanics, atomic physics, and statistical physics requiring an advanced theoretical and mathematical description of phenomena. Scheduled experiments are: Two-Electron Spectra, X-rays and particle-wave duality, Zeeman Effect, Faraday and Kerr Effect, Electron spin and nuclear magnetic resonance, NdYAG laser.

By working in teams of two they will set up experiments, record data, analyze it using appropriate software and error analysis, and present it in a written report. They will finally describe and explain their work in an oral exam.

Intended Learning Outcomes

By the end of the module, students will be able to

1. prepare to conduct experiments and use experimental equipment for a specific physical problem;
2. set up, perform, and evaluate experiments to investigate typical phenomena in quantum mechanics and statistical physics;
3. use experimental techniques and data acquisition tools to record experimental data;
4. analyze the outcomes of experiments by mathematical and computational methods, and use error analysis to assess the accuracy and reproducibility of their results;
5. use the appropriate format and language to summarize and describe an experiment, and communicate its outcome in a scientific report;

6. organize their work and work responsibly in a team to fulfill the given task;
7. orally describe and answer basic questions related to the background, the experimental method and outcome of the experiment.

Indicative Literature

A lab manual will be provided.

Usability and Relationship to other Modules

- Possible elective for a Physics minor

Examination Type: Module Examination

Assessment 1: Lab reports (written and oral components)
Written report — Length: 10-15 pages, Weight: 70%

Scope: Intended learning outcomes (1-6)

Assessment 2: Oral examination — Duration: 30 min, Weight: 30%

Scope: Intended learning outcomes (4,7)

Completion: To pass this module, the examination of each assessment has to be passed with at least 45%.

7.14 Scientific Data Analysis

Module Name			**Module Code**	**Level (type)**	**CP**
Scientific Data Analysis			CO-489	Year 2 (CORE)	5
Module Components					
Number	Name			Type	CP
CO-489-A	Scientific Data Analysis			Lecture	5
Module Coordinator Prof. Dr. Veit Wagner	**Program Affiliation** • Physics and Data Science			**Mandatory Status** Mandatory for PHDS and MMDA Mandatory elective for SDT	
Entry Requirements			**Frequency** Annually (Fall)	**Forms of Learning and Teaching** • Lecture (35 hours) • Homework exercises (55 hours) • Private study (35 hours)	
Pre-requisites ☒ Core Algorithms and Data Structures or Algorithms and Data Structures	Co-requisites ☒ none	Knowledge, Abilities, or Skills • Mathematics at the level of the Mathematical Modelling module • Basic programming skills in Python	**Duration** 1 semester	**Workload** 125 hours	
Recommendations for Preparation Review mathematics/linear algebra/statistics and programming at the level of the first-year courses.					

Content and Educational Aims

Interpretation of scientific data is at the core of knowledge creation in any science. Proper tools and analysis techniques are the foundation for new theory validation against experimental findings, parameter extraction from computational or experimental data, and to discover data relationships in given data sets. This holds for all fields of physics, for the natural sciences in general and for fields beyond. This module provides a calculus-based introduction to analytical techniques applied to scientific data sets. Topics include probability distributions, linear and non-linear least square estimation, Bayesian statistics, Fourier analysis, (time) sequence analysis including power spectra and convolution, principal component analysis, data visualization techniques, as well as error and outlier analysis. Exemplary datasets from experimental and computational sources are used throughout the course. The course introduces their proper handling and data organization in databases. The course is part of the core physics and data science as well as the core mathematics, modeling and data analytics education. It builds on the foundation of the programming lab, the data handling in first year lab courses and first year mathematics foundations. Essential practical experience in applying the various analysis techniques and their visualization will be supported by homework exercises in close coordination with the lectures. The aim of the module is to enable students to properly handle, store, analyze and visualize larger multidimensional scientific datasets by various methods and from various fields, and to prepare students for the data handling in their BSc thesis research. At the same time, students' programming and mathematical repertoires as well as their problem-solving skills are developed. The module also serves as a foundation for specialization subject modules.

Intended Learning Outcomes Upon completion of this module, students will be able to 1. perform curve and model fitting 2. conduct advanced data analysis including Fourier analysis and Bayesian statistics 3. understand error handling in multidimensional complex data analysis 4. store, import, handle and visualize large data sets
Indicative Literature Graham Currell: Scientific Data Analysis, Oxford University Press, 2015. Edward L. Robinson: Data Analysis for Scientists and Engineers, Princeton University Press, 2016.
Usability and Relationship to other Modules
Examination Type: Module Examination Assessment Type: Portfolio (assignments, quizzes) Weight: 100% Scope: All intended learning outcomes of the module Completion: To pass this module, the examination has to be passed with at least 45%

7.15 Machine Learning

Module Name		Module Code	Level (type)	CP
Machine Learning		CO-541	Year 2 (CORE)	5
Module Components				
Number	Name		Type	CP
CO-541-A	Machine Learning		Lecture	5
Module Coordinator Prof. Dr. Francesco Maurelli	**Program Affiliation** • Robotics and Intelligent Systems (RIS)		**Mandatory Status** Mandatory for ACS, RIS, minor in RIS, MMDA, and PHDS Mandatory elective for CS	
Entry Requirements Pre-requisites ☒ None	Co-requisites ☒None	Knowledge, Abilities, or Skills • Knowledge and command of probability theory and methods, as in the module “Probability and Random Process" (JTMS-12)	**Frequency** Annually (Spring) **Duration** 1 semester	**Forms of Learning and Teaching** • Class attendance (35 hours) • Private study (70 hours) • Exam preparation (20 hours) **Workload** 125 hours
Recommendations for Preparation None				

Content and Educational Aims

Machine learning (ML) concerns algorithms that are fed with (large quantities of) real-world data, and which return a compressed “model” of the data. An example is the “world model” of a robot; the input data are sensor data streams, from which the robot learns a model of its environment, which is needed, for instance, for navigation. Another example is a spoken language model; the input data are speech recordings, from which ML methods build a model of spoken English; this is useful, for instance, in automated speech recognition systems. There exist many formalisms in which such models can be cast, and an equally large diversity of learning algorithms. However, there is a relatively small number of fundamental challenges that are common to all of these formalisms and algorithms. The lectures introduce such fundamental concepts and illustrate them with a choice of elementary model formalisms (linear classifiers and regressors, radial basis function networks, clustering, online adaptive filters, neural networks, or hidden Markov models). Furthermore, the lectures also (re-)introduce required mathematical material from probability theory and linear algebra.

Intended Learning Outcomes

By the end of this module, students should be able to

1. understand the notion of probability spaces and random variables;
2. understand basic linear modeling and estimation techniques;
3. understand the fundamental nature of the “curse of dimensionality;”
4. understand the fundamental nature of the bias-variance problem and standard coping strategies;
5. use elementary classification learning methods (linear discrimination, radial basis function networks, multilayer perceptrons);
6. implement an end-to-end learning suite, including feature extraction and objective function optimization with regularization based on cross-validation.

Indicative Literature

T. Hastie, R. Tibshirani, J. Friedman, The Elements of Statistical Learning: Data Mining, Inference, and Prediction, 2nd edition, Springer, 2008.

S. Shalev-Shwartz, Shai Ben-David: Understanding Machine Learning, Cambridge University Press, 2014.

C. Bishop, Pattern Recognition and Machine Learning, Springer, 2006.

T.M. Mitchell, Machine Learning, Mc Graw Hill India, 2017.

Usability and Relationship to other Modules

- This module serves as a third Year Specialization module for CS major students.
- This module gives a thorough introduction to the basics of machine learning. It complements the Artificial Intelligence module.

Examination Type: Module Examination

Assessment Type: Written examination Duration: 120 min

Weight: 100%

Scope: All intended learning outcomes of the module

Completion: To pass this module, the examination has to be passed with at least 45%

7.16 Condensed Matter Physics

Module Name			**Module Code**	**Level (type)**	**CP**
Condensed Matter Physics			CA-S-PHDS-801	Year 3 (Specialization)	5
Module Components					
Number	Name			Type	CP
CA-PHDS-801	Condensed Matter and Devices			Lecture	5
Module Coordinator Prof. Dr. Veit Wagner	**Program Affiliation** • Physics and Data Science			**Mandatory Status** Mandatory elective for PHDS	
Entry Requirements			**Frequency**	**Forms of Learning and Teaching**	
Pre-requisites	Co-requisites	Knowledge, Abilities, or Skills	Annually (Fall)	• Lecture (35 hours) • Homework exercises (45 hours) • Private study (45 hours)	
☒ Statistical Physics	☒ None	• Quantum Mechanics	**Duration** 1 semester	**Workload** 125 hours	
Recommendations for Preparation					
Review statistical mechanics and quantum mechanics at the level of the second-year courses.					

Content and Educational Aims

Technological progress and the development of new materials and devices requires a detailed description and understanding of the physics of matter. This course provides a thorough introduction to condensed matter and solid-state physics. Topics include different forms of condensed matter, crystal types, and crystal structures. Based on classical and quantum mechanical Bose/Fermi statistics and the concepts of density-functional theory, the models by Drude and Sommerfeld, Fermi sphere, cohesive energy, classical and quantum harmonic crystals, phonons, and quasiparticles are introduced, as well as the structure and dynamics of solids, band theory and electronic properties, optical properties, magnetism, and superconductivity. The working principles of important semiconductor devices are explained, including transistors, LEDs, solid-state lasers, and solar cells.

Intended Learning Outcomes

By the end of the module, students will be able to

1. determine the basic properties of gases and condensed matter based on microscopic and statistical models;
2. describe the behavior of electrons and analyze how they influence macroscopic and electronic properties of materials;
3. select basic experimental techniques and procedures needed to study solid state materials;
4. communicate in scientific language using advanced field-specific technical terms.

Indicative Literature
C. Kittel (2018). Introduction to Solid State Physics. Hoboken: Wiley. S. M. Sze & K. K. Lee (2006). Semiconductor Devices: Physics and Technology. Hoboken: Wiley.
Usability and Relationship to other Modules
• Possible elective for a physics minor • Useful foundation for many BSc thesis research topics.
Examination Type: Module Examination
Assessment Type: Written examination — Duration: 120 min, Weight: 100% Scope: All intended learning outcomes of the module. Completion: To pass this module, the examination has to be passed with at least 45%

7.17 Particles, Fields and Quanta

Module Name	Module Code	Level (type)	CP
Particles, Fields and Quanta	CA-S-PHDS-802	Year 3 (Specialization)	5

Module Components

Number	Name	Type	CP
CA-PHDS-802-A	Elementary Particles and Fields	Lecture	2.5
CA-PHDS-802-B	Advanced Quantum Physics	Lecture	2.5

Module Coordinator	Program Affiliation	Mandatory Status
Prof. Dr. Peter Schupp	• Physics and Data Science (PHDS)	Mandatory elective for PHDS and MMDA

Entry Requirements		Frequency	Forms of Learning and Teaching
Pre-requisites	Knowledge, Abilities, or Skills	Annually (Spring)	• Lectures (35 hours) • Homework exercises, project/presentation (55 hours) • Private study (35 hours)
☒ Quantum Mechanics and Analytical Mechanics. Alternatively, for both Foundations of Mathematical Physics	• Mathematics at the level of the Mathematical Modeling module	**Duration** 1 semester	**Workload** 125 hours

Recommendations for Preparation

Review classical mechanics, quantum mechanics, and electrodynamics at the level of the second-year courses.

Content and Educational Aims

This module is devoted to advanced topics in theoretical physics. The first part of the module is devoted to an introductory overview of theoretical and experimental aspects of elementary particle physics, classical and quantum field theory, and (optionally) aspects of nuclear physics and general relativity. The second part of the module introduces advanced methods and concepts of quantum mechanics with applications and an introduction to quantum information theory. The focus may change from year to year reflecting current trends in physics, for example, quantum computing. The topics of the module will include entanglement, perturbation theory, second quantization, introductory quantum field theory, Feynman diagrams, and gauge theories of the fundamental forces of nature (Standard Model). Examples of possible further topics are path integrals, molecular quantum mechanics, spin dynamics, geometric phase and topology, and coherent states.

The physics specialization modules aim to prepare students for their further professional, research, or academic careers in physics and related fields with lectures on important advanced topics in physics, an introduction to scientific research methods and tools, and an exposure to original scientific research literature. Lectures are complemented by homework exercises and student projects that culminate in student presentations and/or term papers.

Intended Learning Outcomes

By the end of the module, students will be able to

1. describe the building blocks of matter and the fundamental forces of nature;
2. calculate quantities of interest in quantum physics like, for example, scattering cross sections or energy levels using perturbation theory and similar advanced methods;
3. formulate models of particle physics and quantum systems and derive their properties;
4. understand the fundamentals of quantum information theory.

Indicative Literature

T. Lancaster (2015). Quantum Field Theory for the Gifted Amateur. Oxford University Press.

M.A. Nielsen, I.L. Chuang (2010). Quantum Computation and Quantum Information. Cambridge University Press.

Selected topics from: J.J. Sakurai. Modern Quantum Mechanics. Cambridge University Press.

Usability and Relationship to other Modules

- Possible elective for a physics minor

Examination Type: Module Examination

Assessment Type: Project with presentation,

Duration of the presentation: 15 min
Weight: 100%

Scope: All intended learning outcomes of the module.

Completion: To pass this module, the examination has to be passed with at least 45%

7.18 Biophysics

Module Name Biophysics			Module Code CA-S-PHDS-804	Level (type) Year 3 (Specialization)	CP 2.5
Module Components					
Number	Name			Type	CP
CA-PHDS-804	Biophysics			Lecture	2.5
Module Coordinator Prof. Dr. Jürgen Fritz	**Program Affiliation** • Physics and Data Science			**Mandatory Status** Mandatory elective for PHDS	
Entry Requirements			**Frequency** Biennially (Spring)	**Forms of Learning and Teaching** • Lectures (17.5 hours) • Homework exercises, project and presentation (27.5 hours) • Private study (17.5 hours)	
Pre-requisites	Co-requisites	Knowledge, Abilities, or Skills			
☒ Modern Physics	☒ None	• None beyond formal pre-requisites	**Duration** 1 semester	**Workload** 62.5 hours	
Recommendations for Preparation None.					

Content and Educational Aims

The Biophysics Module is part of a collection of physics specialization modules that cover topics in advanced experimental physics focusing on biophysics, nanotechnology, advanced optics, and molecular physics. These modules provide an introductory overview of a range of interdisciplinary topics in experimental and computational physics for advanced physics majors. After introductions to the fields, seminal and recent research is discussed, in parts based on original literature.

The physics specialization modules aim to prepare students for their further professional, research, or academic careers in physics and related fields with lectures on important advanced topics in physics, an introduction to scientific research methods and tools, and an exposure to original scientific research literature. Lectures are complemented by homework exercises and/or student projects that culminate in student presentations, term papers or written exams depending on the specific module.

Intended Learning Outcomes

By the end of the module, students will be able to

1. reduce complex systems to their basic physical properties;
2. explain phenomena in biosystems by basic principles from physics;
3. qualitatively but mathematically describe biosystems by their physical properties;
4. communicate in scientific language using advanced field-specific terms.

Indicative Literature Not specified - current research literature
Usability and Relationship to other Modules • Possible elective for a Physics minor
Examination Type: Module Examination Assessment Type: Project with presentation — Duration of the presentation: 10 min Weight: 100% Scope: All intended learning outcomes of the module Completion: To pass this module, the examination has to be passed with at least 45%

7.19 Atoms and Molecules

<table>
<tr><td colspan="3">Module Name
Atoms and Molecules</td><td>Module Code
CA-S-PHDS-805</td><td>Level (type)
Year 3
(Specialization)</td><td>CP
2.5</td></tr>
<tr><td colspan="6">Module Components</td></tr>
<tr><td>Number</td><td colspan="3">Name</td><td>Type</td><td>CP</td></tr>
<tr><td>CA-PHDS-805</td><td colspan="3">Atoms and Molecules</td><td>Lecture</td><td>2.5</td></tr>
<tr><td>Module Coordinator

Prof. Dr. Arnulf Materny</td><td colspan="3">Program Affiliation

• Physics and Data Science</td><td colspan="2">Mandatory Status

Mandatory elective for PHDS</td></tr>
<tr><td rowspan="2">Entry Requirements

Pre-requisites
☒ Modern Physics</td><td rowspan="2">Co-requisites
☒ None</td><td rowspan="2">Knowledge, Abilities, or Skills
• None beyond formal pre-requisites</td><td>Frequency

Biennially (Spring)</td><td colspan="2">Forms of Learning and Teaching

• Lectures (17.5 hours)
• Homework exercises, project and presentation (27.5 hours)
• Private study (17.5 hours)</td></tr>
<tr><td>Duration

1 semester</td><td colspan="2">Workload

62.5 hours</td></tr>
<tr><td colspan="6">Recommendations for Preparation

None.</td></tr>
</table>

Content and Educational Aims

The Atoms & Molecules Module is part of a collection of physics specialization modules that cover topics in advanced experimental physics focusing on biophysics, nanotechnology, advanced optics, and molecular physics. These modules provide an introductory overview of a range of interdisciplinary topics in experimental and computational physics for advanced physics majors. The aim of these seminar-style lectures is to enable students to dive into the research on more complex and molecular systems and their optical characterization. After introductions to the fields, seminal and recent research is discussed, in parts based on original literature.

The physics specialization modules aim to prepare students for their further professional, research, or academic careers in physics and related fields with lectures on important advanced topics in physics, an introduction to scientific research methods and tools, and an exposure to original scientific research literature. Lectures are complemented by homework exercises and/or student projects that culminate in student presentations, term papers or written exams depending on the specific module.

Intended Learning Outcomes

By the end of the module, students will be able to

1. reduce complex systems to their basic physical properties;
2. explain the principles of the electronic properties of atoms and molecules including basic theoretical and experimental techniques to probe these properties;
3. communicate in scientific language using advanced field-specific terms.

Indicative Literature Not specified - current research literature
Usability and Relationship to other Modules • Possible elective for a Physics minor
Examination Type: Module Examination Assessment Type: Project with presentation Duration of the presentation: 10 min Weight: 100% Scope: All intended learning outcomes of the module Completion: To pass this module, the examination has to be passed with at least 45%

7.20 Nanotechnology

Module Name			Module Code	Level (type)	CP
Nanotechnology			CA-S-PHDS-806	Year 3 (Specialization)	2.5
Module Components					
Number	Name			Type	CP
CA-PHDS-806	Nanotechnology			Lecture	2.5
Module Coordinator Prof. Dr. Jürgen Fritz	**Program Affiliation** • Physics and Data Science			**Mandatory Status** Mandatory elective for PHDS	
Entry Requirements			**Frequency** Biennially (Spring)	**Forms of Learning and Teaching** • Lectures (17.5 hours) • Homework exercises, project and presentation (27.5 hours) • Private study (17.5 hours)	
Pre-requisites	Co-requisites	Knowledge, Abilities, or Skills			
☒ Modern Physics	☒ None	• None beyond formal pre-requisites	**Duration** 1 semester	**Workload** 62.5 hours	

Recommendations for Preparation

None.

Content and Educational Aims

The Nanotechnology Module is part of a collection of physics specialization modules that cover topics in advanced experimental physics focusing on biophysics, nanotechnology, advanced optics, and molecular physics. These modules provide an introductory overview of a range of interdisciplinary topics in experimental and computational physics for advanced physics majors. After introductions to the fields, seminal and recent research is discussed, in parts based on original literature.

The physics specialization modules aim to prepare students for their further professional, research, or academic careers in physics and related fields with lectures on important advanced topics in physics, an introduction to scientific research methods and tools, and an exposure to original scientific research literature. Lectures are complemented by homework exercises and/or student projects that culminate in student presentations, term papers or written exams depending on the specific module.

Intended Learning Outcomes

By the end of the module, students will be able to

1. reduce complex systems to their basic physical properties;
2. explain phenomena in nanosystems by basic principles from physics;
3. qualitatively but mathematically describe nanosystems by their physical properties;
4. communicate in scientific language using advanced field-specific terms.

Indicative Literature

Not specified - current research literature

Usability and Relationship to other Modules

- Possible elective for a Physics minor

Examination Type: Module Examination

Assessment Type: Project with presentation

Duration of the presentation: 10 min

Weight: 100%

Scope: All intended learning outcomes of the module

Completion: To pass this module, the examination has to be passed with at least 45%

7.21 Advanced Optics

Module Name			Module Code	Level (type)	CP
Advanced Optics			CA-S-PHDS-807	Year 3 (Specialization)	2.5
Module Components					
Number	Name			Type	CP
CA-PHDS-807	Advanced Optics			Lecture	2.5
Module Coordinator Prof. Dr. Arnulf Materny	**Program Affiliation** • Physics and Data Science (PHDS)			**Mandatory Status** Mandatory elective for PHDS	
Entry Requirements Pre-requisites ☒ Modern Physics	Co-requisites ☒ None	Knowledge, Abilities, or Skills • None beyond formal pre-requisites	**Frequency** Biennially (Spring)	**Forms of Learning and Teaching** • Lectures (17.5 hours) • Homework exercises, project and presentation (27.5 hours) • Private study (17.5 hours)	
			Duration 1 semester	**Workload** 62.5 hours	
Recommendations for Preparation None.					

Content and Educational Aims

The Advanced Optics Module is part of a collection of physics specialization modules that cover topics in advanced experimental physics focusing on biophysics, nanotechnology, advanced optics, and molecular physics. These modules provide an introductory overview of a range of interdisciplinary topics in experimental and computational physics for advanced physics majors. After introductions to the fields, seminal and recent research is discussed, in parts based on original literature.

The physics specialization modules aim to prepare students for their further professional, research, or academic careers in physics and related fields with lectures on important advanced topics in physics, an introduction to scientific research methods and tools, and an exposure to original scientific research literature. Lectures are complemented by homework exercises and/or student projects that culminate in student presentations, term papers or written exams depending on the specific module.

Intended Learning Outcomes

By the end of the module, students will be able to

1. Understanding of experimental optics (geometric and wave optics);
2. application of techniques allowing for the numerical simulation of optical elements;
3. communicate in scientific language using advanced field-specific terms.

Indicative Literature

Not specified - current research literature

Usability and Relationship to other Modules • Possible elective for a Physics minor
Examination Type: Module Examination Assessment Type: Written Examination Duration: 90 min Weight: 100% Scope: All intended learning outcomes of the module Completion: To pass this module, the examination has to be passed with at least 45%

7.22 Deep Learning

<table>
<tr><td colspan="3">Module Name
Deep Learning</td><td>Module Code
MCSSE-AI-01</td><td>Level (type)
Year 1 / 2</td><td>CP
5</td></tr>
<tr><td colspan="6">Module Components</td></tr>
<tr><td>Number</td><td colspan="3">Name</td><td>Type</td><td>CP</td></tr>
<tr><td>MCSSE-AI-01</td><td colspan="3">Deep Learning</td><td>Lecture</td><td>5</td></tr>
<tr><td>Module Coordinator

Prof. Dr. Alexander Omelchenko</td><td colspan="3">Program Affiliation

• MSc Computer Science & Software Engineering</td><td colspan="2">Mandatory Status

Mandatory elective for CSSE and PHDS</td></tr>
<tr><td colspan="3" rowspan="2">Entry Requirements

Pre-requisites: ☒ none
Co-requisites: ☒ none
Knowledge, Abilities, or Skills:
• Strong knowledge and abilities in mathematics (linear algebra, calculus).</td><td>Frequency

Annually (Fall)</td><td colspan="2">Forms of Learning and Teaching

• Lectures (35 hours)
• Private study (70 hours)
• Exam preparation (20 hours)</td></tr>
<tr><td>Duration

1 Semester</td><td colspan="2">Workload

125 hours</td></tr>
</table>

Recommendations for Preparation

This module is recommended for students that have been exposed to core knowledge in machine learning / statistical learning on undergraduate level. Students without this background knowledge can still join since required core knowledge is re-introduced. Preparation via auxiliary literature or online courses will facilitate the start into the course.

Content and Educational Aims

In machine learning we aim at extracting meaningful representations, patterns and regularities from high-dimensional data. In recent years, researchers from various disciplines have developed “deep” hierarchical models, i.e. models that consist of multiple layers of nonlinear processing. An important property of these models is that they can “learn” by reusing and combining intermediate concepts, so that these models can be used successfully in a variety of domains, including information retrieval, natural language processing, and visual object detection. After a brief introduction into core knowledge related to training, model evaluation and multilayer perceptrons, this module focuses on the exposing students to deep learning techniques including convolutional and recurrent neural networks, autoencoders, generative adversarial networks and reinforcement learning. The central aim is hence to enable students to critically assess and apply modern methods in machine learning.

Intended Learning Outcomes

Upon completion of this module, students will be able to

1. Understand core techniques to train neural networks
2. Select from modern neural network architectures the most appropriate method (e.g. convolutional and recurrent neural networks) based on given input data
3. Contrast different recent unsupervised learning methods including autoencoders and generative adversarial networks
4. Describe techniques in reinforcement learning.

Indicative Literature

Ian Goodfellow, Yoshua Bengio, Aaron Courville: Deep Learning, MIT Press, 2016.

Aurélien Géron: Hands-On Machine Learning with Scikit-Learn, Keras & TensorFlow, 2nd Edition, O’Reilly, 2019.

Christopher M. Bishop: Pattern Recognition and Machine Learning, Springer, 2006.

Charu C. Aggarwal: Neural Networks and Deep Learning – A Textbook, Springer, 2018.

Usability and Relationship to other Modules While the graduate level modules “Data Analytics” and “Machine Learning” provide an applied introduction to the field and are therefore recommended for students with a focus on Software Engineering or Cybersecurity, this module complements the undergraduate module “Machine Learning” or can be used independently as a strong introduction to the field of Deep Learning.
Examination Type: Module Examination Assessment: Written Examination Duration: 120 min Weight: 100% Scope: All intended learning outcomes of the module. Completion: To pass this module, the examination has to be passed with at least 45%

7.23 Data Visualization and Image Processing

Module Name			Module Code	Level (type)	CP
Data Visualization and Image Processing			MDE-CO-05	Year 2 (CORE)	5
Module Components					
Number	Name			Type	CP
MDE-CO-05	Data Visualization and Image Processing			Lecture	5
Module Coordinator	**Program Affiliation**			**Mandatory Status**	
Prof. Dr. Stefan Kettemann	• MSc Data Engineering			Mandatory for DE Mandatory elective for PHDS	
Entry Requirements			**Frequency**	**Forms of Learning and Teaching**	
Pre-requisites	Co-requisites	Knowledge, Abilities, or Skills	Annually (Fall)	• Lectures (35 hours) • Private Study, incl. exercises and exam preparation (90 hours)	
☒ None	☒ None	• Basic linear algebra, calculus and programming skills			
			Duration	**Workload**	
			1 semester	125 hours	

Recommendations for Preparation

Read the syllabus.

Content and Educational Aims

This module introduces the basic concepts of (1) data visualization and (2) image processing.

(1) Computer-based visualization systems provide visual representations of datasets intended to help people carry out certain task more effectively. These datasets can come from very diverse sources, such as scientific experiments, simulations, medical scanners, commercial databases, financial trans-actions, health records, social networks and the like. In the This module deals with effective visual mappings as well as interaction principles for various data, to develop an understanding of the perceptual and cognitive aspects of visual representations. Students learn how to evaluate visualization systems.

(2) The second half of the module focuses on image processing and delves into questions of how we can digitally process image data. Topics include for instance sampling and quantization strategies, image segmentation, image transformations, noise reduction and feature extraction.

Intended Learning Outcomes

Upon completion of this module, students will be able to:

1. represent and interact with various data visually;
2. evaluate visual depictions of data and find possible improved presentations;
3. assist users in visual data analysis;
4. understand transforms and being able to apply them to 2D images.

Indicative Literature

M. O. Ward, G. Grinstein, D. Keim, Interactive Data Visualization: Foundations, Techniques, and Applications, Second Edition, Matthew O. Ward, Georges Grinstein, Daniel Keiml, 2015, ISBN, 9781482257373.

A. C. Telea, Data Visualization: Principles and Practice, Second Edition, A K Peters, 2014, ISBN, 9781466585263.

Usability and Relationship to other Modules

- As this module introduces visualization techniques for data sets, it builds on courses introducing data systems, particularly the Data Analytics module MDE-CO-02 and the Data Mining module MDE-BSC-01.

Examination Type: Module Examination

Assessment Type: Written Examination — Duration: 120 minutes — Weight: 100%

Scope: All intended learning outcomes of this module.

Completion: To pass this module, the examination has to be passed with at least 45%

7.24 Stochastic Modeling and Financial Mathematics

Module Name			Module Code	Level (type)	CP
Stochastic Modeling and Financial Mathematics			CA-S-MMDA-803	Year 2 and 3 (Specialization)	5
Module Components					
Number	Name			Type	CP
CA-MMDA-803	Stochastic Modeling and Financial Mathematics			Lecture	5
Module Coordinator	**Program Affiliation** • Mathematics, Modeling, and Data Analytics (MMDA)			**Mandatory Status** Mandatory elective for SDT,MMDA, PHDS and RIS	
Entry Requirements			**Frequency** Annually (Spring/Fall)	**Forms of Learning and Teaching** • Lectures (35 hours) • Private Study (90 hours)	
Pre-requisites	Co-requisites	Knowledge, Abilities, or Skills			
☒ Matrix Algebra and Advanced Calculus I & II	☒ none	• Good command of Calculus, Linear Algebra, and basic probability basic Python programming	**Duration** 1 semester	**Workload** 125 hours	

Recommendations for Preparation

- Review the content of Matrix Algebra & Advanced Calculus II
- Review Python programming
- Pre-install Anaconda Python on your own laptop and know how to edit and start simple Python programs in a Python IDE like Spyder (which comes bundled as part of Anaconda Python).

Content and Educational Aims

This module is a first hands-on introduction to stochastic modeling. Examples will mostly come from the area of Financial Mathematics, so that this module plays a central role in the education of students interested in Quantitative Finance and Mathematical Economics. The module is taught as an integrated lecture-lab, where short theoretical units are interspersed with interactive computation and computer experiments.

Topics include a short introduction to the basic notions of financial mathematics, binomial tree models, discrete Brownian paths, stochastic integrals and ODEs, Ito's Lemma, Monte-Carlo methods, finite differences solutions, the Black-Scholes equation, and an introduction to time series analysis, parameter estimation, and calibration. Towards the end, the Fokker-Planck equation, Ornstein-Uhlenbeck processes, and nonlinear Stochastic Partial Differential Equations are discussed, and connections to applications in physics and other areas of mathematics are made. Students will program and explore all basic techniques in a numerical programming environment and apply these algorithms to real data whenever possible.

Intended Learning Outcomes

Upon completion of this module, students will be able to

1. apply fundamental concepts of deterministic and stochastic modeling;
2. design, conduct, and interpret controlled in-silico scientific experiments;
3. analyze the basic concepts of financial mathematics and their role in finance;
4. write computer code for basic financial calculations, binomial trees, stochastic differential equations, stochastic integrals and time series analysis;
5. compare their programs and predictions in the context of real data;
6. demonstrate the usage of a version control system for collaboration and the submission of code and reports.

Indicative Literature

- Y.-D. Lyuu (2002). Financial Engineering and Computation - Principles, Mathematics, Algorithms. Cambridge: Cambridge University Press.
- J.C. Hull (2015). Options, Futures and other Derivatives, 9th edition. New York: Pearson.
- Etheridge (2002). A Course in Financial Calculus. Cambridge: Cambridge University Press.
- D.J. Higham (2001). An Algorithmic Introduction to Numerical Simulation of Stochastic Differential Equations, SIAM Rev. 43(3):525-546.
- D.J. Higham (2004). Black-Scholes Option Valuation for Scientific Computing Students, Computing in Science & Engineering 6(6):72-79.

Usability and Relationship to other Modules

- This module is part of the core education in Mathematics, Modelling and Data Analytics.
- It is also valuable for students in Physics and Data Science, Computer Science, Data Engineering, RIS, and ECE, either as part of a minor in Mathematics, or as an elective module.

Examination Type: Module Examination

Assessment Type: Portfolio (programming assessments, project) Weight: 100%

Scope: All intended learning outcomes of this module

Completion: To pass this module, the examination has to be passed with at least 45%

7.25 Quantum Informatics

Module Name	Module Code	Level (type)	CP
Quantum Informatics	MCSSE-BT-01	Year 2	5

Module Components

Number	Name	Type	CP
MCSSE-BT-01-A	Quantum Informatics	Lecture	2.5
MCSSE-BT-01-B	Quantum Informatics Lab	Lab	2.5

Module Coordinators	Program Affiliation	Mandatory Status
Prof. Dr. Peter Schupp, Prof. Dr. Stefan Kettemann	• MSc Computer Science & Software Engineering	Mandatory elective for MSc CSSE Mandatory elective for BSc MMDA and PHDS

Entry Requirements			Frequency	Forms of Learning and Teaching
Pre-requisites	Co-requisites	Knowledge, Abilities, or Skills	Annually	- Lectures (17.5 hours) - Lab/precepts (17.5 hours) - Private study incl. exercises, projects, and exam preparation (90 hours)
☒ none	☒ none	• Basic linear algebra	**Duration** 1 semester	**Workload** 125 hours

Recommendations for Preparation

Introductory texts on quantum mechanics, quantum information and quantum computing; review of vectors and matrices

Content and Educational Aims

This module features a self-contained introduction to Quantum Informatics, one of the fastest growing emergent fields in science and technology, including essential elements from physics and mathematics. Topics include an overview of current quantum technology; pertinent aspects of quantum mechanics and information theory; qubits, quantum registers, quantum gates; no-cloning theorem, deferred and implicit quantum measurement; circuit model of quantum computing; quantum communication, cryptography and attacks; Grover, Shor and further quantum algorithms; post-quantum cryptography; decoherence, quantum channels, quantum error correction; physical qubits; variational and adiabatic quantum computing, quantum annealing; quantum simulation; quantum programming and quantum SDKs.

The lectures are complemented by a lab, where concepts are further deepened and practically applied. Part of the lab will be in precept-style with exercises, part will involve hands-on practical experience including mini projects.

Intended Learning Outcomes

Upon completion of this module, students will be able to:

1. Discuss the state of the art of quantum computing and quantum communication.
2. Apply the principles of quantum theory to analyze quantum circuits.
3. Develop quantum algorithms and quantum communication protocols.
4. Assess applications of quantum informatics

Indicative Literature

Michael A. Nielsen, Isaac L. Chuang: Quantum Computation and Quantum Information (10th Anniversary Edition), Cambridge University Press, 2010
N. David Mermin: Quantum Computer Science: An Introduction, Cambridge University Press, 2007

Usability and Relationship to other Modules

Module Component Examinations

Module Component 1: Final Exam

Assessment Type: Written examination Duration/length: 120 min

Weight: 50%

Scope: all ILOs (focus on theory).

Module Component 2: Lab Assessment

Assessment Type: Portfolio (Graded Exercises, Project Work)

Weight: 50%

Scope: all ILOs (focus on practical application).

Completion: To pass this module, the examination of each module component has to be passed with at least 45%

7.26 Foundation of Mathematical Physics

Module Name			**Module Code**	**Level (type)**	**CP**
Foundations of Mathematical Physics			CA-S-MATH-806	Year 2/3 (Specialization)	5
Module Components					
Number	Name			Type	CP
CA-MATH-806	Foundations of Mathematical Physics			Lecture	5
Module Coordinator Prof. Dr. Sören Petrat	**Program Affiliation** • Mathematics, Modeling and Data Analytics (MMDA)			**Mandatory Status** Mandatory elective for MMDA and PHDS	
Entry Requirements Pre-requisites ☒ Mathematical Modeling	Co-requisites ☒None	Knowledge, Abilities, or Skills • Good command of linear algebra, analysis, and calculus	**Frequency** Biennially (Fall)	**Forms of Learning and Teaching** • Lectures (35 hours) • Private study (90 hours)	
			Duration 1 semester	**Workload** 125 hours	

Recommendations for Preparation

Review material from pre-requisite modules, especially Applied Mathematics. Having taken Applied Mathematics is recommended.

Content and Educational Aims

This module is about the application of mathematics in physics. Physics and mathematics have a very intimate relationship. On the one hand, big discoveries in physics have often led to interesting new mathematics, and on the other hand, new developments in mathematics have made possible new discoveries in physics. The goal of this module is to look at some examples of that, and to gain an insight what role rigorous mathematics has played and plays today in explaining physical phenomena. This class discusses examples from the major theories of classical mechanics, quantum mechanics, electrodynamics, and statistical mechanics.

A selection of the following topics will be covered:

- Mathematical foundations of classical mechanics
- Hamiltonian dynamics and symplectic geometry
- Integrable systems
- Special functions
- Mathematical foundations of quantum mechanics
- Quantum entanglement
- Fourier analysis
- Variational methods
- Non-linear partial differential equations from physics
- Scattering theory
- Many-body quantum mechanics and second quantization
- Geometric foundations (differential geometry)
- Mathematical problems in statistical mechanics and other fields of physics

Intended Learning Outcomes

By the end of the module, students will be able to

1. demonstrate the application of mathematics in the context of physics
2. explain the mathematical foundations of classical mechanics, quantum mechanics, statistical physics, and electrodynamics
3. discuss the solutions to both linear and non-linear equations in physics
4. breakdown the Hamiltonian formalism in the context of classical and quantum mechanics
5. apply variational methods and their role in minimization and maximization problems

Indicative Literature

S.J. Gustafson, I.M. Sigal (2010). Mathematical Concepts of Quantum Mechanics, 2nd edition. Berlin: Springer.

G. Teschl (2014). Mathematical Methods in Quantum Mechanics, 2nd edition. Rhode Island: AMS.

W. Thirring (1997). Classical Mathematical Physics - Dynamical Systems and Field Theories, 3rd edition, Berlin: Springer.

W. Thirring (2002). Quantum Mathematical Physics - Atoms, Molecules and Large Systems, 2nd edition. Berlin: Springer.

Usability and Relationship to other Modules

-

Examination Type: Module Examination

Assessment Type: Written examination Duration: 120 min
Scope: All intended learning outcomes of this module Weight: 100%

Completion: To pass this module, the examination has to be passed with at least 45%

7.27 Topology and Differential Geometry

Module Name			Module Code	Level (type)	CP
Topology and Differential Geometry			CA-S-MMDA-801	Year 2 and 3 (Specialization)	5
Module Components					
Number	Name			Type	CP
CA-MMDA-801	Topology and Differential Geometry			Lecture	5
Module Coordinator	**Program Affiliation**			**Mandatory Status**	
Prof. Dr. Sören Petrat	• Mathematics, Modelling, and Data Analytics (MMDA)			Mandatory Elective for MMDA and PHDS.	
Entry Requirements			**Frequency**	**Forms of Learning and Teaching**	
Pre-requisites	Co-requisites	Knowledge, Abilities, or Skills	Annually (Spring/Fall)	• Lectures (35 hours) • Private Study (90 hours)	
☒ Analysis	☒ none	• Good command of Analysis and Linear Algebra	**Duration** 1 semester	**Workload** 125 hours	

Recommendations for Preparation

- Recap basic Analysis and Linear Algebra knowledge

Content and Educational Aims

In the first part, building on first results in point-set topology, which have already appeared in the context of metric spaces in Analysis I, the abstract notions of a topology and of continuity are introduced. Particular results on continuous functions and families thereof, e.g., the Tietze extension theorem and the Arzela-Ascoli compactness theorem, are proved. The basic construction of a metric, Urysohn's Lemma, and the Baire Theorem are likewise proved. Associated topological spaces such as fiber bundles and mapping spaces will be introduced and analyzed.

The second part deals with Calculus on Manifolds. The notions of manifolds and differentiable structures are introduced, and mappings between manifolds are studied. Further topics are vector fields, differential forms, integration on manifolds, and the important Stokes' Theorem. At the end, we will briefly discuss Lie groups and Riemannian Geometry.

Intended Learning Outcomes

Upon completion of this module, students will be able to

1. give precise proofs of basic set-theoretical topological results in the appropriate level of abstraction
2. make a catalog of examples and counterexamples for the basic concepts in set-theoretical topology
3. define the notions of manifolds and structures on them
4. describe how calculus on manifolds is used
5. explain and apply Stokes' Theorem

Indicative Literature

- Bredon, G. E. (2013). Topology and geometry (Vol. 139). Springer Science & Business Media.
- Lee, J. M. (2013). Smooth manifolds. In Introduction to smooth manifolds (pp. 1-31). Springer, New York, NY.

Usability and Relationship to other Modules

Examination Type: Module Examination

Assessment Type: Written examination Duration/length: 120 min

Weight: 100%

Scope: All intended learning outcomes of this module

Completion: To pass this module, the examination has to be passed with at least 45%

7.28 Physical Chemistry

Module Name Physical Chemistry			Module Code CO-440	Level (type) Year 2 (CORE)	CP 5
Module Components					
Number	Name			Type	CP
CO-440-A	Physical Chemistry			Lecture	5
Module Coordinator Prof. Dr. Detlef Gabel	**Program Affiliation** • Chemistry and Biotechnology (CBT)			**Mandatory Status** Mandatory for CBT, minor CBT mandatory elective for PHDS and MCCB	
Entry Requirements Pre-requisites ☒ General and Inorganic Chemistry or ☒ Modern Physics	Co-requisites ☒ None	Knowledge, Abilities, or Skills • None beyond formal prerequisites	**Frequency** Annually (Fall)	**Forms of Learning and Teaching** • Lecture (45 hours) • Private study (45 hours) • Exam preparation (35 hours	
			Duration 2 semesters	**Workload** 125 hours	
Recommendations for Preparation None					

Content and Educational Aims

The module introduces Physical Chemistry with a focus on thermodynamics, kinetics, intermolecular forces, surfaces, and electrochemistry, as well as also quantum chemistry. This knowledge is essential to understand when chemical reactions can take place and how fast they can occur, and how molecules interact with each other and the solvent.

Intended Learning Outcomes

By the end of the module, the student will be able to

1. use the gas laws to predict the behavior of perfect and real gases;
2. differentiate between enthalpy, entropy, and Gibbs energy;
3. correlate Gibbs energy with equilibrium constants;
4. derive the velocities of reactions of zero, first, and the second order;
5. derive the velocities of enzyme reactions and coupled reactions;
6. explain and apply the concept of activation energy;
7. calculate the velocity of reactions as a function of temperature;
8. recognize phase transitions from measurable properties;
9. explain and apply fundamentals in electrochemistry;
10. explain how given molecules and their functional groups can interact with each other and their surroundings;
11. recognize the different approaches to quantum chemical calculations;
12. use an electronic lab book and share their own results with others through it;
13. derive the fundamental equations of importance in physical chemistry;
14. demonstrate presentation skills;

Indicative Literature

Atkins and de Paula, Elements of Physical Chemistry, 7th edition. Oxford: Oxford University Press, 2017.

Usability and Relationship to other Modules

Examination Type: Module Examination
Assessment Component 1: Written examination — Duration: 120 min. Weight: 75%
Scope: Intended learning outcomes of the module (1-12)
Assessment Component 2: Presentation — Duration 15 min Weight 25%
Scope: Intended learning outcomes of the module (13-14)
Completion: This module is passed with an assessment-component weighted average grade of 45% or higher.

7.29 Electronics

<table>
<tr><td colspan="3">Module Name
Electronics</td><td>Module Code
CO-526</td><td>Level (type)
Year 2 (CORE)</td><td>CP
5</td></tr>
<tr><td colspan="6">Module Components</td></tr>
<tr><td>Number</td><td colspan="3">Name</td><td>Type</td><td>CP</td></tr>
<tr><td>CO-526-A</td><td colspan="3">Electronics</td><td>Lecture</td><td>2.5</td></tr>
<tr><td>CO-526-B</td><td colspan="3">Electronics Lab</td><td>Lab</td><td>2.5</td></tr>
<tr><td>Module Coordinator

Dr. Mathias Bode</td><td colspan="3">Program Affiliation

• Electrical and Computer Engineering (ECE)</td><td colspan="2">Mandatory Status

Mandatory for ECE
Mandatory elective for PHDS</td></tr>
<tr><td colspan="3" rowspan="2">Entry Requirements

Pre-requisites: ☒ General Electrical Engineering I&II
Or
☒Electrodynamics and Relativity (Physics)

Co-requisites: ☒ None

Knowledge, Abilities, or Skills:
• Linear circuits
• Basic Calculus
• Basic Linear Algebra</td><td>Frequency

Annually (Fall)</td><td colspan="2">Forms of Learning and Teaching

• Lecture (17,5 hours)
• Lab (25.5 hours)
• Private Study (82.00)</td></tr>
<tr><td>Duration

1 semester</td><td colspan="2">Workload

125 hours</td></tr>
<tr><td colspan="6">Recommendations for Preparation

Revise linear circuits from your 1st year, and get textbook & lab material. See dedicated module Web pages for details (links on CampusNet).</td></tr>
<tr><td colspan="6">Content and Educational Aims

Electronics and circuits are at the core of modern technology. This module comprises a lecture and a lab component. It builds on the 1st year General Electrical Engineering modules and provides a more in-depth coverage of the analysis and, in particular, the design of linear and nonlinear analog circuits. After a recap on linear circuits techniques, the lecture gives an introduction to fundamental nonlinear electronic devices, and electronic circuits. Starting from semiconductor properties, the operation principles and various applications of diodes, bipolar junction transistors (BJTs), and field-effect transistors (MOSFETs) are discussed. Different electronic circuits are analyzed and designed including rectifiers, voltage doublers, single- and multi-stage amplifiers, and operational amplifier (OpAmp) stages. While the lecture emphasizes theoretical concepts, the lab provides practical experience and allows the students to relate concrete hardware to device and circuit models. LTSpice are used for the simulation of the basic components and circuits. Experiments include RLC circuits, filters and resonators, diodes, pn-junctions and their application, bipolar junction transistors (BJT) and elementary transistor circuits including amplifiers, differential amplifiers and the basics of operational amplifiers, application of operational amplifiers. MOS field effect transistors and their application in amplifiers and inverter circuits.</td></tr>
</table>

Intended Learning Outcomes

By the end of this module, students should be able to

1. explain fundamental electronic devices;
2. analyze and design electronic circuits, in particular linear networks, amplifiers, and operational amplifier circuits, based on a modular approach;
3. compare different designs with regard to their performance figures like voltage gain, current gain, band width;
4. operate lab equipment (oscilloscopes, electric sources, voltmeters) to investigate DC and AC circuits.

Indicative Literature

David Comer and Donald Comer, Fundamentals of Electronic Circuit Design, Wiley, 2002.

Usability and Relationship to other Modules

- This module builds on the GenEE1 and GenEE2 modules (as well as on physics CORE module Electrodynamics) and prepares the students for practical specializations in their 3rd year.

Examination Type: Module Component Examination

Module Component 1: Lecture

Assessment Type: Written examination Duration: 120 min
Weight: 50%
Scope: Intended learning outcomes of the lecture (1-3).

Module Component 2: Lab

Assessment Type: Lab reports Length: 5-10 pages per experiment session
Weight: 50%
Scope: Intended learning outcomes of the lab (2-4).

Completion: To pass this module, the examination of each module component has to be passed with at least 45%.

7.30 Information Theory

<table>
<tr><td colspan="3">Module Name
Information Theory</td><td>Module Code
CO-525</td><td>Level (type)
Year 2 (CORE)</td><td>CP
5</td></tr>
<tr><td colspan="6">Module Components</td></tr>
<tr><td>Number</td><td colspan="3">Name</td><td>Type</td><td>CP</td></tr>
<tr><td>CO-525-A</td><td colspan="3">Information Theory</td><td>Lecture</td><td>5</td></tr>
<tr><td>Module Coordinator

Prof. Dr.-Ing. Werner Henkel</td><td colspan="3">Program Affiliation

• Electrical and Computer Engineering (ECE)</td><td colspan="2">Mandatory Status

Mandatory for ECE
Mandatory elective for CS, RIS, and PHDS</td></tr>
<tr><td rowspan="2">Entry Requirements

Pre-requisites

☒ None</td><td rowspan="2">

Co-requisites

☒ None</td><td rowspan="2">

Knowledge, Abilities, or Skills

• Signals and Systems contents, such as DFT and convolution
• Notion of probability, combinatorics basics as taught in Methods module “Probability and Random Processes"</td><td>Frequency

Annually (Spring)</td><td colspan="2">Forms of Learning and Teaching

• Lectures (35 hours)
• Private Study (90 hours)</td></tr>
<tr><td>Duration

1 semester</td><td colspan="2">Workload

125 hours</td></tr>
<tr><td colspan="6">Recommendations for Preparation

Some basic knowledge of communications and sound understanding of probability is recommended. Hence, it is strongly advised to take the methods and skills course Probability and Random Processes prior to this module. Nevertheless, probability basics will also be revised within the module.</td></tr>
<tr><td colspan="6">Content and Educational Aims

Information theory serves as the most important foundation for communication systems. The module provides an analytical framework for modeling and evaluating point-to-point and multi-point communication. After a short rehearsal of probability and random variables and some excursion to random number generation, the key concept of information content of a signal source and information capacity of a transmission medium are precisely defined, and their relationships to data compression algorithms and error control codes are examined in detail. The module aims to install an appreciation for the fundamental capabilities and limitations of information transmission schemes and to provide the mathematical tools for applying these ideas to a broad class of communications systems.
The module contains also a coverage of different source-coding algorithms like Huffman, Lempel-Ziv-(Welch), Shannon-Fano-Elias, Arithmetic Coding, Runlength Encoding, Move-to-Front transform, PPM, and Context Tree Weighting. In Channel coding, finite fields, some basic block and convolutional codes, and the concept of iterative decoding will be introduced. Aside from source and channel aspects, an introduction to security is given, including public-key cryptography.
Information theory is a standard module in every communications-oriented Bachelor’s program.</td></tr>
<tr><td colspan="6">Intended Learning Outcomes

By the end of this module, students should be able to

1. explain what is understood as the information content of data and the corresponding limits of data compression algorithms;
2. design and apply fundamental algorithms in data compression;
3. explain the information theoretic limits of data transmission;
4. apply the mathematical basics of channel coding and cryptography;
5. implement some channel coding schemes;
6. differentiate the principles of encryption and authentication schemes and implement discussed procedures.</td></tr>
</table>

Indicative Literature

Thomas M. Cover, Joy A. Thomas, Elements of Information Theory, 2nd ed., Wiley, Sept. 2006.
David Salomon, Data Compression, The Complete Reference, 4th ed., Springer, 2007.

Usability and Relationship to other Modules

- Although not a mandatory prerequisite, this module is ideally taken before Coding Theory (CA-ECE-802)
- All communications-related modules are naturally based on information theory
- Students from Computer Science or related programs, also students taking Bio-informatics modules, profit from information-theoretic knowledge and source coding (compression) algorithms. Students from Computer Science would also be interested in the algebraic basics for error-correcting codes and cryptology, fields which area also introduced shortly.

Examination Type: Module Examination

Assessment Type: Written examination Duration: 120 min
Weight: 100%

Scope: All intended learning outcomes of the module.

Completion: To pass this module, the examination has to be passed with at least 45%.

7.31 Internship / Startup and Career Skills

<table>
<tr><td colspan="3">Module Name
Internship / Startup and Career Skills</td><td>Module Code
CA-INT-900</td><td>Level (type)
Year 3
(CAREER)</td><td>CP
15</td></tr>
<tr><td colspan="6">Module Components</td></tr>
<tr><td>Number</td><td colspan="3">Name</td><td>Type</td><td>CP</td></tr>
<tr><td>CA-INT-900-0</td><td colspan="3">Internship</td><td>Internship</td><td>15</td></tr>
<tr><td>Module Coordinator

Sinah Vogel & Dr. Tanja Woebs (CSC Organization); SPC / Faculty Startup Coordinator (Academic responsibility)</td><td colspan="3">Program Affiliation

• CAREER module for undergraduate study programs</td><td colspan="2">Mandatory Status

Mandatory for all undergraduate study programs except IEM</td></tr>
<tr><td colspan="3">Entry Requirements</td><td rowspan="3">Frequency

Annually
(Spring/Fall)</td><td colspan="2" rowspan="3">Forms of Learning and Teaching

• Internship/Start-up
• Internship event
• Seminars, info-sessions, workshops and career events
• Self-study, readings, online tutorials</td></tr>
<tr><td>Pre-requisites</td><td>Co-requisites</td><td>Knowledge, Abilities, or Skills</td></tr>
<tr><td rowspan="2">☒ at least 15 CP from CORE modules in the major</td><td rowspan="2">☒ None</td><td rowspan="2">• Information provided on CSC pages (see below)
• Major specific knowledge and skills</td></tr>
<tr><td>Duration
1 semester</td><td colspan="2">Workload

375 Hours consisting of:
• Internship (308 hours)
• Workshops (33 hours)
• Internship Event (2 hours)
• Self-study (32 hours)</td></tr>
<tr><td colspan="6">Recommendations for Preparation

• Please see the section “Knowledge Center” at JobTeaser Career Center for information on Career Skills seminar and workshop offers and for online tutorials on the job market preparation and the application process. For more information, please see https://constructor.university/student-life/career-services
• Participating in the internship events of earlier classes</td></tr>
<tr><td colspan="6">Content and Educational Aims

The aims of the internship module are reflection, application, orientation, and development: for students to reflect on their interests, knowledge, skills, their role in society, the relevance of their major subject to society, to apply these skills and this knowledge in real life whilst getting practical experience, to find a professional orientation, and to develop their personality and in their career. This module supports the programs’ aims of preparing students for gainful, qualified employment and the development of their personality

The full-time internship must be related to the students’ major area of study and extends lasts a minimum of two consecutive months, normally scheduled just before the 5th semester, with the internship event and submission of the internship report in the 5th semester. Upon approval by the SPC and SCS, the internship may take place at other times, such as before teaching</td></tr>
</table>

starts in the 3rd semester or after teaching finishes in the 6th semester. The Study Program Coordinator or their faculty delegate approves the intended internship a priori by reviewing the tasks in either the Internship Contract or Internship Confirmation from the respective internship institution or company. Further regulations as set out in the Policies for Bachelor Studies apply.

Students will be gradually prepared for the internship in semesters 1 to 4 through a series of mandatory information sessions, seminars, and career events. The purpose of the Student Career Support Information Sessions is to provide all students with basic facts about the job market in general, and especially in Germany and the EU, and services provided by the Student Career Support.

In the Career Skills Seminars, students will learn how to engage in the internship/job search, how to create a competitive application (CV, Cover Letter, etc.), and how to successfully conduct themselves at job interviews and/or assessment centers. In addition to these mandatory sections, students can customize their skill set regarding application challenges and their intended career path in elective seminars.

Finally, during the Career Events organized by the Student Career Support (e.g. the annual Constructor Career Fair and single employer events on and off campus), students will have the opportunity to apply their acquired job market skills in an actual internship/job search situation and to gain their desired internship in a high-quality environment and with excellent employers.

As an alternative to the full-time internship, students can apply for the StartUp Option. Following the same schedule as the full-time internship, the StartUp Option allows students who are particularly interested in founding their own company to focus on the development of their business plan over a period of two consecutive months. Participation in the StartUp Option depends on a successful presentation of the student’s initial StartUp idea. This presentation will be held at the beginning of the 4th semester. A jury of faculty members will judge the student’s potential to realize their idea and approve the participation of the students. The StartUp Option is supervised by the Faculty StartUp Coordinator. At the end of StartUp Option, students submit their business plan. Further regulations as outlined in the Policies for Bachelor Studies apply.

The concluding Internship Event will be conducted within each study program (or a cluster of related study programs) and will formally conclude the module by providing students the opportunity to present on their internships and reflect on the lessons learned within their major area of study. The purpose of this event is not only to self-reflect on the whole internship process, but also to create a professional network within the academic community, especially by entering the Alumni Network after graduation. It is recommended that all three classes (years) of the same major are present at this event to enable networking between older and younger students and to create an educational environment for younger students to observe the “lessons learned” from the diverse internships of their elder fellow students.

Intended Learning Outcomes

By the end of this module, students should be able to

1. describe the scope and the functions of the employment market and personal career development;
2. apply professional, personal, and career-related skills for the modern labor market, including self-organization, initiative and responsibility, communication, intercultural sensitivity, team and leadership skills, etc.;
3. independently manage their own career orientation processes by identifying personal interests, selecting appropriate internship locations or start-up opportunities, conducting interviews, succeeding at pitches or assessment centers, negotiating related employment, managing their funding or support conditions (such as salary, contract, funding, supplies, workspace, etc.);
4. apply specialist skills and knowledge acquired during their studies to solve problems in a professional environment and reflect on their relevance in employment and society;
5. justify professional decisions based on theoretical knowledge and academic methods;
6. reflect on their professional conduct in the context of the expectations of and consequences for employers and their society;
7. reflect on and set their own targets for the further development of their knowledge, skills, interests, and values;
8. establish and expand their contacts with potential employers or business partners, and possibly other students and alumni, to build their own professional network to create employment opportunities in the future;
9. discuss observations and reflections in a professional network.

Indicative Literature

Not specified

Usability and Relationship to other Modules

• This module applies skills and knowledge acquired in previous modules to a professional environment and provides an opportunity to reflect on their relevance in employment and society. It may lead to thesis topics.
Examination Type: Module Examination Assessment Type: Internship Report or Business Plan and Reflection   Length: approx. 3.500 words Scope: All intended learning outcomes   Weight: 100%

7.32 Thesis and Seminar Physics and Data Science

Module Name		Module Code	Level (type)	CP
Bachelor Thesis PHDS		CA-PHDS-800	Year 3 (CAREER)	15
Module Components				
Number	Name		Type	CP
CA-PHDS-800-S	Thesis Seminar PHDS		Seminar	3
CA-PHDS-800-T	Bachelor Thesis PHDS		Project work	12
Module Coordinator Prof. Dr. Peter Schupp, Prof. Dr. Veit Wagner	**Program Affiliation** • Physics and Data Science		**Mandatory Status** Mandatory for PHDS	
Entry Requirements Pre-requisites ☒ Students must have taken and successfully passed a total of at least 30 CP from advanced modules, and of those, at least 20 CP from advanced modules in the major.	Co-requisites ☒ None	Knowledge, Abilities, or Skills • Academic writing skills	**Frequency** Annually (Spring)	**Forms of Learning and Teaching** • Seminar (40 hours) • Project work (200 hours) • Private study (135 hours)
			Duration 14-week lecture period	**Workload** 375 hours

Recommendations for Preparation

- Students need to recap their knowledge in the specific field of their thesis.
- Identify an area or a topic of interest and discuss this with your prospective supervisor in good time.
- Create a research proposal including a research plan to ensure timely submission.
- Ensure you possess all required technical research skills or can acquire them on time.
- Review the University's Code of Academic Integrity and Guidelines to Ensure Good Academic Practice.

Content and Educational Aims

Within this module, students use their knowledge in physics and data science, and their mathematical and experimental skills gained during their studies, to become acquainted with a research topic. They will demonstrate their mastery of the content and methods of a specific research field in physics and data science as provided by faculty. The seminar part is devoted to research preparation (reading, discussing, presenting) and is typically organized by research groups. For the thesis students will familiarize themselves with a research topic and conduct physics and/or data science research under guidance by faculty and research group members. The thesis can include experimental, theoretical and/or computational aspects, the description and documentation of results, and the discussion and interpretation of outcomes. Results will be presented in a Physics and Data Science Thesis Colloquium (as part of the seminar) and will be written up and documented in a Bachelor Thesis according to the scientific standards in Physics and Data Science.

Intended Learning Outcomes

By the end of the module, students will be able to

1. familiarize themselves with a new field in physics and/or data science, by finding, reviewing, and understanding the relevant scientific literature;
2. prepare for a specific research problem in physics and/or data science by researching the necessary experimental techniques and/or theoretical, computational, and mathematical approaches;
3. use and apply the appropriate experimental or theoretical/mathematical/computational techniques to solve a problem;
4. analyze the outcome of their research work and evaluate it through discussions with senior scientists;
5. organize their work and work responsibly and independently in a research team to fulfill a given task or solve a given problem;
6. use the appropriate format and language to summarize and describe their findings in a scientific report (thesis);
7. answer basic questions related to the background, the method used, and the outcomes of their research project;

use the appropriate language of the scientific community to communicate, discuss, and defend scientific findings and ideas in physics and data science.

Usability and Relationship to other Modules

- Mandatory CAREER modules for the Physics and Data Science major.

This module builds on all previous modules of the program. Students apply the knowledge, skills and competencies they acquired and practiced during their studies, including research methods and the ability to independently acquire additional skills as and if required.

Examination Type: Module Component Examinations

Module Component 1: Thesis/Project

Assessment Type: Thesis (Thesis) — Length: 20-30 pages; Weight: 80%

Scope: All intended learning outcomes.

Module Component 2: Seminar

Type: Presentation (Seminar) — Duration: 15-30 minutes; Weight: 20%

Scope: Intended learning outcomes 1, 2, 4, 7, 8.

Completion: To pass this module, both module component examinations have to be passed with at least 45%.

8 CONSTRUCTOR Track Modules

8.1 Methods

8.1.1 Matrix Algebra and Advanced Calculus I

<table>
<tr><td colspan="3">Module Name
Matrix Algebra and Advanced Calculus I</td><td>Module Code
CTMS-MAT-22</td><td>Level (type)
Year 1
(Methods)</td><td>CP
5</td></tr>
<tr><td colspan="6">Module Components</td></tr>
<tr><td>Number</td><td colspan="3">Name</td><td>Type</td><td>CP</td></tr>
<tr><td>CTMS-22</td><td colspan="3">Matrix Algebra and Advanced Calculus I</td><td>Lecture</td><td>5</td></tr>
<tr><td>Module Coordinator
Dr. Keivan Mallahi-Karai</td><td colspan="3">Program Affiliation

• CONSTRUCTOR Track Area</td><td colspan="2">Mandatory Status

Mandatory for ECE and SDT MMDA, PHDS.
Mandatory elective for CS, and RIS</td></tr>
<tr><td colspan="3" rowspan="2">Entry Requirements

Pre-requisites: ☒ none
Co-requisites: ☒ none
Knowledge, Abilities, or Skills:
• Knowledge of pre-calculus ideas (sets and functions, elementary functions, polynomials) and analytic geometry (equations of lines, systems of linear equations, dot product, polar coordinates) at High School level. Familiarity with ideas of calculus is helpful.</td><td>Frequency

Annually
(Spring/Fall)</td><td colspan="2">Forms of Learning and Teaching</td></tr>
<tr><td>Duration

1 semester</td><td colspan="2">125 hours</td></tr>
<tr><td colspan="6">Recommendations for Preparation
Review of high school mathematics.</td></tr>
<tr><td colspan="6">Content and Educational Aims

This module is the first in a sequence including advanced mathematical methods at the university level at a level higher than the course Calculus and Linear Algebra I. The course comprises the following topics:

• Number systems, complex numbers
• The concept of function, composition of functions, inverse functions
• Basic ideas of calculus: Archimedes to Newton
• The notion of limit for functions and sequences and series
• Continuous function and their basic properties
• Derivatives: rate of change, velocity and applications
• Mean value theorem and estimation, maxima and minima, convex functions
• Integration, change of variables, Fundamental Theorem of Calculus
• Applications of the integral: work, area, average value, centre of mass
• Improper Integrals, Mean value theorem for integrals
• Taylor series
• Ordinary differential equations, examples, solving first order linear differential equations
• Basic ideas of numerical analysis, Newton's method, asymptotic formulas
• Review of elementary analytic geometry, lines, conics
• Vector spaces, linear independence, bases, coordinates
• Linear maps, matrices and their algebra, matrix inverses</td></tr>
</table>

- Gaussian elimination, solution space
- Determinants

Intended Learning Outcomes

Upon completion of this module, students will be able to

1. apply the methods described in the content section of this module description to the extent that they can
2. solve standard text-book problems reliably and with confidence;
3. recognize the mathematical structures in an unfamiliar context and translate them into a mathematical problem statement;
4. recognize common mathematical terminology used in textbooks and research papers in the quantitative sciences, engineering, and mathematics to the extent that they fall into the content categories covered in this module.

Indicative Literature

Advanced Calculus, G.B. Folland (Pearson, 2002)

Linear Algebra, S. Lang (Springer Verlag, 1986)

Mathematical Methods for Physics and Engineering,

K. Riley, M. Hobson, S. Bence (Cambridge University Press, 2006)

Usability and Relationship to other Modules

- Calculus and Linear Algebra I can be substituted with this module after consulting academic advisor
- A more advanced treatment of multi-variable Calculus, in particular, its applications in Physics and Mathematics, is provided in the second-semester module "Applied Mathematics". All students taking "Applied Mathematics" are expected to take this module as well as the module topics are closely synchronized.
- The second-semester module "Linear Algebra" provides a complete proof-driven development of the theory of Linear Algebra. Diagonalization is covered more abstractly, with particular emphasis on degenerate cases. The Jordan normal form is also covered in "Linear Algebra", not in this module.

Examination Type: Module Examination

Assessment Type: Written examination Duration: 120 min
Weight: 100%

Scope: All intended learning outcomes of the module.

Completion: To pass this module, the examination has to be passed with at least 45%

8.1.2 Matrix Algebra and Advanced Calculus II

Module Name		Module Code	Level (type)	CP
Matrix Algebra and Advanced Calculus II		CTMS-MAT-23	Year 1 (Methods)	5
Module Components				
Number	Name		Type	CP
CTMS-23	Matrix Algebra and Advanced Calculus II		Lecture	5

Module Coordinator	**Program Affiliation**	**Mandatory Status**
Dr. Keivan Mallahi Karai	• CONSTRUCTOR Track Area	Mandatory for SDT, ECE, MMDA and PHDS Mandatory elective for CS and RIS

Entry Requirements			**Frequency**	**Forms of Learning and Teaching**
Pre-requisites	Co-requisites	Knowledge, Abilities, or Skills	Annually (Spring)	• Lectures (35 hours) • Private study (90 hours)
☒ Matrix Algebra and Advanced Calculus I	☒ none	• None beyond formal pre-requisites	**Duration** 1 semester	**Workload** 125 hours

Recommendations for Preparation

Review the content of Matrix Algebra and Advanced Calculus I

Content and Educational Aims

- Coordinate systems, functions of several variables, level curves, polar coordinates
- Continuity, directional derivatives, partial derivatives, chain rule (version I)
- derivative as a matrix, chain rule (version II), tangent planes and linear approximation, gradient, repeated partial derivatives
- Minima and Maxima of functions of several variables, Lagrange multipliers
- Multiple integrals, iterated integrals, integration over standard regions, change of variables formula
- Vector fields, parametric representation of curves, line integrals and arc length, conservative vector fields
- Potentials, Green's theorem in the plane
- Parametric representation of surfaces
- Vector products and normal surface integrals
- Integral theorems by Stokes and Gauss, physical interpretations
- Basics of differential forms and their calculus, connection to gradient, curl, and divergence
- Eigenvalues and eigenvectors, diagonalisable matrices
- Inner product spaces, Hermitian and unitary matrices
- Matrix factorizations: Singular value decomposition with applications, LU decomposition, QR decomposition
- Linear constant-coefficient ordinary differential equations, application to mechanical vibrations and electrical oscillations
- Periodic functions, Fourier series

Intended Learning Outcomes

Upon completion of this module, students will be able to

1. understand the definitions of continuity, derivative of a function as a linear transformation, multivariable integrals, eigenvalues and eigenvectors and associated notions.
2. apply the methods described in the content section of this module description to the extent that they can
3. evaluate multivariable integrals using definitions or by applying Green and Stokes theorem.
4. evaluate various decompositions of matrices
5. solve standard text-book problems reliably and with confidence;

6. recognize the mathematical structures in an unfamiliar context and translate them into a mathematical problem statement;
7. recognize common mathematical terminology used in textbooks and research papers in the quantitative sciences, engineering, and mathematics to the extent that they fall into the content categories covered in this module.

Indicative Literature

Advanced Calculus, G.B. Folland (Pearson, 2002)

Linear Algebra, S. Lang (Springer Verlag, 1986)

Mathematical Methods for Physics and Engineering,

K. Riley, M. Hobson, S. Bence (Cambridge University Press, 2006)

Vector Calculus, Linear Algebra, and Differential Forms: A Unified

Approach, J.H. Hubbard, B. Hubbard (Pearson, 1998)

Usability and Relationship to other Modules

- This module can substitute Calculus and Linear Algebra II after consulting academic advisor.
- Methods of this course are applied in the module Mathematical Modeling.
- The second-semester module Linear Algebra provides a more rigorous and more abstract treatment of some of the notions discussed in this module.

Examination Type: Module Examination

Assessment type: Written examination

Length/duration: (120min)
Weight: 100 %

Scope: All intended learning outcomes of this module

Completion: To pass this module, the examination has to be passed with at least 45%

8.1.3 Probability and Random Processes

Module Name		Module Code	Level (type)	CP
Probability and Random Processes		CTMS-MAT-12	Year 2 (Methods)	5
Module Components				
Number	Name		Type	CP
CTMS-12	Probability and random processes		Lecture	5
Module Coordinator	**Program Affiliation**		**Mandatory Status**	
Dr. Keivan Mallahi Karai,	• CONSTRUCTOR Track Area		Mandatory for CS, SDT, ECE, MMDA, PHDS and RIS	

Entry Requirements			**Frequency**	**Forms of Learning and Teaching**
Pre-requisites	Co-requisites	Knowledge, Abilities, or Skills	Annually (Fall)	• Lectures (35 hours) • Private study (90 hours)
☒ Matrix Algebra and Advanced Calculus II or Calculus and Linear Algebra II	☒ None	• Knowledge of calculus at the level of a first year calculus module (differentiation, integration with one and several variables, trigonometric functions, logarithms and exponential functions). • Knowledge of linear algebra at the level of a first-year university module (eigenvalues and eigenvectors, diagonalization of matrices). • Some familiarity with elementary probability theory at the high school level.	**Duration** 1 semester	**Workload** 125 hours

Recommendations for Preparation

Review all of the first-year calculus and linear algebra modules as indicated in "Entry Requirements – Knowledge, Ability, or Skills" above.

Content and Educational Aims

This module aims to provide a basic knowledge of probability theory and random processes suitable for students in engineering, Computer Science, and Mathematics. The module provides students with basic skills needed for formulating real-world problems dealing with randomness and probability in mathematical language, and methods for applying a toolkit to solve these problems. Mathematical rigor is used where appropriate. A more advanced treatment of the subject is deferred to the third-year module Stochastic Processes.

The lecture comprises the following topics

- Brief review of number systems, elementary functions, and their graphs
- Outcomes, events and sample space.
- Combinatorial probability.
- Conditional probability and Bayes' formula.
- Binomials and Poisson-Approximation
- Random Variables, distribution and density functions.
- Independence of random variables.
- Conditional Distributions and Densities.
- Transformation of random variables.
- Joint distribution of random variables and their transformations.
- Expected Values and Moments, Covariance.
- High dimensional probability: Chebyshev and Chernoff bounds.
- Moment-Generating Functions and Characteristic Functions,
- The Central limit theorem.
- Random Vectors and Moments, Covariance matrix, Decorrelation.
- Multivariate normal distribution.
- Markov chains, stationary distributions.

Intended Learning Outcomes

By the end of the module, students will be able to

1. command the methods described in the content section of this module description to the extent that they can solve standard text-book problems reliably and with confidence;
2. recognize the probabilistic structures in an unfamiliar context and translate them into a mathematical problem statement;
3. recognize common mathematical terminology used in textbooks and research papers in the quantitative sciences, engineering, and mathematics to the extent that they fall into the content categories covered in this module.

Indicative Literature

J. Hwang and J.K. Blitzstein (2019). Introduction to Probability, second edition. London: Chapman & Hall.

S. Ghahramani. Fundamentals of Probability with Stochastic Processes, fourth edition. Upper Saddle River: Prentice Hall.

Usability and Relationship to other Modules

- Students taking this module are expected to be familiar with basic tools from calculus and linear algebra.

Examination Type: Module Examination

Assessment type: Written examination — Duration: 120 min — Weight: 100%

Scope: All intended learning outcomes of this module

Completion: To pass this module, the examination has to be passed with at least 45%

8.1.4 Statistics and Data Analytics

Module Name			Module Code	Level (type)	*CP*
Statistics and Data Analytics			CTMS-MET-21	Year 2 (Methods)	5
Module Components					
Number					
CTMS-21	Statistics and Data Analytics			Lecture	5
Module Coordinator	**Program Affiliation**			**Mandatory Status**	
Dr. Ivan Ovsyannikov	• CONSTRUCTOR Track Area			Mandatory for SDT, MMDA and PHDS	
Entry Requirements			**Frequency**	**Forms of Learning and Teaching**	
Pre-requisites	Co-requisites	Knowledge, Abilities, or Skills	Annually (Spring)	• Lectures (35 hours) • Private Study (105 hours)	
☒ Probability and Random Processes	☒ none	• Good command of basic probability	**Duration**	**Workload**	
			1 semester	120 hours	
Recommendations for Preparation					
Recap Probability and Random Processes					

Content and Educational Aims

The aims of this module is to introduce students to basic ideas and methods used for analysing large and complex datasets. While the first modern statistical toolkits date back to the beginning of the twentieth century, the advent of computer age and the availability of fast computations has lead to dramatic changes in the field.

Statistical models have found applications in many areas ranging from business and healthcare to astrophysics and speech recognition. Such models are used to make predictions, draw inferences and support policy decisions in all these areas.

This module draws on students' knowledge from the module Probability and Random Processes to help them build and analyze statistical models, ranging in their degree of sophistication from basis to more advanced ones, and apply them to real-world situations. The module will cover the following topics:

- Classical statistics: descriptive and inferential modes, parameter estimation and hypothesis testing.
- Linear regressions, multiple linear regressions
- Classification: logistic regression, generative models for classification
- Resampling methods, bootstrap
- Non-linear models, splines
- Support vector machines
- Basic ideas of deep learning

Intended Learning Outcomes

Upon completion of this module, students will be able to

1. formulate statistical models for real world problems
2. describe statistical methods for analyzing real world problems
3. explain the importance of linear and non-linear models
4. recognize different solution methods for modeling problems
5. illustrate the use of regressions, resampling, support vector machines and other statistical tools to describe phenomena in the real world
6. Describe basic ideas of deep learning

Indicative Literature

James, Witten, Hastie, Tibshirani. An introduction to Statistical learning; second edition.

Usability and Relationship to other Modules

- This module is part of the core education in Mathematics, Modeling and Data Analytics and Physics and Data Science.
- It is also valuable for students in Computer Science, RIS, and ECE, either as part of a minor in Mathematics, or as an elective module.

Examination Type: Module Examination

Assessment Type: Written examination Duration/length: 120 min

Weight: 100%

Scope: All intended learning outcomes of this module

Completion: To pass this module, the examination has to be passed with at least 45%

8.2 New Skills

8.2.1 Logic (perspective I)

Module Name Logic (perspective I)		**Module Code** CTNS-NSK-01	**Level (type)** Year 2 (New Skills)	**CP** 2.5
Module Components				
Number	Name		Type	CP
CTNS-01	Logic (perspective I)		Lecture (online)	2.5
Module Coordinator Prof. Dr. Jules Coleman	**Program Affiliation** • CONSTRUCTOR Track Area		**Mandatory Status** Mandatory elective for all UG students (one perspective must be chosen)	
Entry Requirements Pre-requisites ☒ none	Co-requisites ☒ none	Knowledge, Abilities, or Skills •	**Frequency** Annually (Fall)	**Forms of Learning and Teaching** Online lecture (17.5h) Private study (45h)
			Duration 1 semester	**Workload** 62.5 hours
Recommendations for Preparation				

Content and Educational Aims

Suppose a friend asks you to help solve a complicated problem? Where do you begin? Arguably, the first and most difficult task you face is to figure out what the heart of the problem actually is. In doing that you will look for structural similarities between the problem posed and other problems that arise in different fields that others may have addressed successfully. Those similarities may point you to a pathway for resolving the problem you have been asked to solve. But it is not enough to look for structural similarities. Sometimes relying on similarities may even be misleading. Once you've settled tentatively on what you take to be the heart of the matter, you will naturally look for materials, whether evidence or arguments, that you believe is relevant to its potential solution. But the evidence you investigate of course depends on your formulation of the problem, and your formulation of the problem likely depends on the tools you have available – including potential sources of evidence and argumentation. You cannot ignore this interactivity, but you can't allow yourself to be hamstrung entirely by it. But there is more. The problem itself may be too big to be manageable all at once, so you will have to explore whether it can be broken into manageable parts and if the information you have bears on all or only some of those parts. And later you will face the problem of whether the solutions to the particular sub problems can be put together coherently to solve the entire problem taken as a whole.

What you are doing is what we call engaging in computational thinking. There are several elements of computational thinking illustrated above. These include: Decomposition (breaking the larger problem down into smaller ones); Pattern recognition (identifying structural similarities); Abstraction (ignoring irrelevant particulars of the problem): and Creating Algorithms), problem-solving formulas.

But even more basic to what you are doing is the process of drawing inferences from the material you have. After all, how else are you going to create a problem-solving formula, if you draw incorrect inferences about what information has shown and what, if anything follows logically from it. What you must do is apply the rules of logic to the information to draw inferences that are warranted.

We distinguish between informal and formal systems of logic, both of which are designed to indicate fallacies as well as warranted inferences. If I argue for a conclusion by appealing to my physical ability to coerce you, I prove nothing about the truth of what I claim. If anything, by doing so I display my lack of confidence in my argument. Or if the best I can do is berate you for your skepticism, I have done little more than offer an ad hominem instead of an argument. Our focus will be on formal systems of logic, since they are at the heart of both scientific argumentation and computer developed algorithms. There are in fact many different kinds of logic and all figure to varying degrees in scientific inquiry. There are inductive types of logic, which purport to formalize the relationship between premises that if true offer evidence on behalf of a conclusion and the conclusion and are represented as claims about the extent to which the conclusion is confirmed by the premises. There are deductive types of logic, which introduce a different relationship between premise and conclusion. These variations of logic consist in rules that if followed entail that if the premises are true then the conclusion too must be true.

There are also modal types of logic which are applied specifically to the concepts of necessity and possibility, and thus to the relationship among sentences that include either or both those terms. And there is also what are called deontic logic, a modification of logic that purport to show that there are rules of inference that allow us to infer what we ought to do from facts about the circumstances in which we find ourselves. In the natural and social sciences most of the emphasis has been placed on inductive logic, whereas in math it is placed on deductive logic, and in modern physics there is an increasing interest in the concepts of possibility and necessity and thus in modal logic. The humanities, especially normative discussions in philosophy and literature are the province of deontic logic.

This module will also take students through the central aspects of computational thinking, as it is related to logic; it will introduce the central concepts in each, their relationship to one another and begin to provide the conceptual apparatus and practical skills for scientific inquiry and research.

Intended Learning Outcomes

Students acquire transferable and key skills in this module.

By the end of this module, the students will be able to

1. apply the various principles of logic and expand them to computational thinking.
2. understand the way in which logical processes in humans and in computers are similar and different at the same time.
3. apply the basic rules of first-order deductive logic and employ them rules in the context of creating a scientific or social scientific study and argument.
4. employ those rules in the context of creating a scientific or social scientific study and argument.

Indicative Literature

Frege, Gottlob (1879), Begriffsschrift, eine der arithmetischen nachgebildete Formelsprache des reinen Denkens [Translation: A Formal Language for Pure Thought Modeled on that of Arithmetic],Halle an der Salle: Verlag von Louis Nebert.

Gödel, Kurt (1986), Russels mathematische Logik. In: Alfred North Whitehead, Bertrand Russell: Principia Mathematica. Vorwort, S. V–XXXIV. Suhrkamp.

Leeds, Stephen. "George Boolos and Richard Jeffrey. Computability and logic. Cambridge University Press, New York and London1974, x+ 262 pp." The Journal of Symbolic Logic 42.4 (1977): 585-586.

Kubica, Jeremy. Computational fairy tales. Jeremy Kubica, 2012.

McCarthy, Timothy. "Richard Jeffrey. Formal logic: Its scope and limits. of XXXVIII 646. McGraw-Hill Book Company, New York etc. 1981, xvi+ 198 pp." The Journal of Symbolic Logic 49.4 (1984): 1408-1409.

Usability and Relationship to other Modules

Examination Type: Module Examination

Assessment Type: Written Examination

Duration: 60 min
Weight: 100%

Scope: All intended learning outcomes of the module.

Completion: To pass this module, the examination has to be passed with at least 45%

8.2.2 Logic (perspective II)

Module Name			Module Code	Level (type)	CP
Logic (perspective II)			CTNS-NSK-02	Year 2 (New Skills)	2.5
Module Components					
Number	Name			Type	CP
CTNS-02	Logic (perspective II)			Lecture (online)	2.5
Module Coordinator **NN**	**Program Affiliation** • CONSTRUCTOR Track Area			**Mandatory Status** Mandatory elective for all UG students (one perspective must be chosen)	
Entry Requirements Pre-requisites ☒ none	Co-requisites ☒ none	Knowledge, Abilities, or Skills •	**Frequency** Annually (Fall)	**Forms of Learning and Teaching** Online lecture (17.5h) Private study (45h)	
			Duration 1 semester	**Workload** 62.5 hours	
Recommendations for Preparation					

Content and Educational Aims

The focus of this module is on formal systems of logic, since they are at the heart of both scientific argumentation and computer developed algorithms. There are in fact many kinds of logic and all figure to varying degrees in scientific inquiry. There are inductive types of logic, which purport to formalize the relationship between premises that if true offer evidence on behalf of a conclusion and the conclusion and are represented as claims about the extent to which the conclusion is confirmed by the premises. There are deductive types of logic, which introduce a different relationship between premise and conclusion. These variations of logic consist in rules that if followed entail that if the premises are true then the conclusion too must be true.

This module introduces logics that go beyond traditional deductive propositional logic and predicate logic and as such it is aimed at students who are already familiar with basics of traditional formal logic. The aim of the module is to provide an overview of alternative logics and to develop a sensitivity that there are many different logics that can provide effective tools for solving problems in specific application domains.

The module first reviews the principles of a traditional logic and then introduces many-valued logics that distinguish more than two truth values, for example true, false, and unknown. Fuzzy logic extends traditional logic by replacing truth values with real numbers in the range 0 to 1 that are expressing how strong the believe into a proposition is. Modal logics introduce modal operators expressing whether a proposition is necessary or possible. Temporal logics deal with propositions that are qualified by time. Once can view temporal logics as a form of modal logics where propositions are qualified by time constraints. Interval temporal logic provides a way to reason about time intervals in which propositions are true.

The module will also investigate the application of logic frameworks to specific classes of problems. For example, a special subset of predicate logic, based on so-called Horn clauses, forms the basis of logic programming languages such as Prolog. Description logics, which are usually decidable logics, are used to model relationships and they have applications in the semantic web, which enables search engines to reason about resources present on the Internet.

Intended Learning Outcomes

Students acquire transferable and key skills in this module.

By the end of this module, the students will be able to

1. apply the various principles of logic

2. explain practical relevance of non-standard logic
3. describe how many-valued logic extends basic predicate logic
4. apply basic rules of fuzzy logic to calculate partial truth values
5. sketch basic rules of temporal logic
6. implement predicates in a logic programming language
7. prove some simple non-standard logic theorems

Indicative Literature

- Bergmann, Merry. “An Introduction to Many-Valued and Fuzzy Logic: Semantics, Algebras, and Derivation Systems”, Cambridge University Press, April 2008.
- Sterling, Leon S., Ehud Y. Shapiro, Ehud Y. "The Art of Prolog", 2nd edition, MIT Press, March 1994.
- Fisher, Michael. “An Introduction to Practical Formal Methods Using Temporal Logic”, Wiley, Juli 2011.
- Baader, Franz. "The Description Logic Handbook: Theory Implementation and Applications", Cambridge University Press, 2nd edition, May 2010.

Usability and Relationship to other Modules

Examination Type: Module Examination

Assessment Type: Written Examination Duration/Length: 60 min
Weight: 100%

Scope: All intended learning outcomes of the module.

Completion: To pass this module, the examination has to be passed with at least 45%

8.2.3 Causation and Correlation (perspective I)

<table>
<tr><td colspan="2">Module Name
Causation and Correlation (perspective I)</td><td>Module Code
CTNS-NSK-03</td><td>Level (type)
Year 2
(New Skills)</td><td>CP
2.5</td></tr>
<tr><td colspan="5">Module Components</td></tr>
<tr><td>Number</td><td colspan="2">Name</td><td>Type</td><td>CP</td></tr>
<tr><td>CTNS-03</td><td colspan="2">Causation and Correlation</td><td>Lecture (online)</td><td>2.5</td></tr>
<tr><td>Module Coordinator

Prof. Dr. Jules Coleman</td><td colspan="2">Program Affiliation

• CONSTRUCTOR Track Area</td><td colspan="2">Mandatory Status

Mandatory elective for all UG students (one perspective must be chosen)</td></tr>
<tr><td colspan="2" rowspan="2">Entry Requirements

Pre-requisites: ☒ none
Co-requisites: ☒ none
Knowledge, Abilities, or Skills: •</td><td>Frequency

Annually (Spring)</td><td colspan="2">Forms of Learning and Teaching

Online lecture (17.5h)
Private study (45h)</td></tr>
<tr><td>Duration

1 semester</td><td colspan="2">Workload

62.5 hours</td></tr>
<tr><td colspan="5">Recommendations for Preparation</td></tr>
<tr><td colspan="5">Content and Educational Aims

In many ways, life is a journey. And also, as in other journeys, our success or failure depends not only on our personal traits and character, our physical and mental health, but also on the accuracy of our map. We need to know what the world we are navigating is actually like, the how, why and the what of what makes it work the way it does. The natural sciences provide the most important tool we have developed to learn how the world works and why it works the way it does. The social sciences provide the most advanced tools we have to learn how we and other human beings, similar in most ways, different in many others, act and react and what makes them do what they do. In order for our maps to be useful, they must be accurate and correctly reflect the way the natural and social worlds work and why they work as they do.

The natural sciences and social sciences are blessed with enormous amounts of data. In this way, history and the present are gifts to us. To understand how and why the world works the way it does requires that we are able to offer an explanation of it. The data supports a number of possible explanations of it. How are we to choose among potential explanations? Explanations, if sound, will enable us to make reliable predictions about what the future will be like, and also to identify many possibilities that may unfold in the future. But there are differences not just in the degree of confidence we have in our predictions, but in whether some of them are necessary future states or whether all of them are merely possibilities? Thus, there are three related activities at the core of scientific inquiry: understanding where we are now and how we got here (historical); knowing what to expect going forward (prediction); and exploring how we can change the paths we are on (creativity).

At the heart of these activities are certain fundamental concepts, all of which are related to the scientific quest to uncover immutable and unchanging laws of nature. Laws of nature are thought to reflect <u>a causal</u> nexus between a previous event and a future one. There are also true statements that reflect universal or nearly universal connections between events past and present that are not laws of nature because the relationship they express is that of <u>a correlation</u> between events. A working thermostat accurately allows us to determine or even to predict the temperature in the room in which it is located, but it does not explain why the room has the temperature it has. What then is the core difference between causal relationships and correlations? At the same time, we all recognize that given where we are now there are many possible futures for each of us, and even had our lives gone just the slightest bit differently than they have, our present state could well have been very different than it is. The relationship between possible pathways between events that have not materialized but could have is expressed through the idea of <u>counterfactual.</u></td></tr>
</table>

Creating accurate roadmaps, forming expectations we can rely on, making the world a more verdant and attractive place requires us to understand the concepts of causation, correlation, counterfactual explanation, prediction, necessity, possibility, law of nature and universal generalization. This course is designed precisely to provide the conceptual tools and intellectual skills to implement those concepts in our future readings and research and ultimately in our experimental investigations, and to employ those tools in various disciplines.

Intended Learning Outcomes

Students acquire transferable and key skills in this module.

By the end of this module, the students will be able to

1. formulate testable hypotheses that are designed to reveal causal connections and those designed to reveal interesting, important and useful correlations.
2. distinguish scientifically interesting correlations from unimportant ones.
3. apply critical thinking skills to evaluate information.
4. understand when and why inquiry into unrealized possibility is important and relevant.

Indicative Literature

Thomas S. Kuhn: The Structure of Scientific Revolutions, Nelson, fourth edition 2012;

Goodman, Nelson. Fact, fiction, and forecast. Harvard University Press, 1983;

Quine, Willard Van Orman, and Joseph Silbert Ullian. The web of belief. Vol. 2. New York: Random house, 1978.

Usability and Relationship to other Modules

Examination Type: Module Examination

Assessment Type: Written Examination

Duration/Length: 60 min
Weight: 100%

Scope: All intended learning outcomes of the module

Completion: To pass this module, the examination has to be passed with at least 45%

8.2.4 Causation and Correlation (perspective II)

Module Name		**Module Code**	**Level (type)**	**CP**
Causation and Correlation (perspective II)		CTNS-NSK-04	Year 2 (New Skills)	2.5
Module Components				
Number	Name		Type	CP
CTNS-04	Causation and Correlations (perspective II)		Lecture (online)	2.5
Module Coordinator Dr. Keivan Mallahi-Karai Dr. Eoin Ryan Dr. Irina Chiaburu	**Program Affiliation** • CONSTRUCTOR Track Area		**Mandatory Status** Mandatory elective for all UG students (one perspective must be chosen)	

Entry Requirements			**Frequency**	**Forms of Learning and Teaching**
Pre-requisites	Co-requisites	Knowledge, Abilities, or Skills	Annually (Spring)	Online lecture (17.5h) Private study (45h)
☒ none	☒ none	• Basic probability theory		
			Duration 1 semester	**Workload** 62.5 hours

Recommendations for Preparation

Content and Educational Aims

Causality or causation is a surprisingly difficult concept to understand. David Hume famously noted that causality is a concept that our science and philosophy cannot do without, but it is equally a concept that our science and philosophy cannot describe. Since Hume, the problem of cause has not gone away, and sometimes seems to get even worse (e.g., quantum mechanics confusing previous notions of causality). Yet, ways of doing science that lessen our need to explicitly use causality have become very effective (e.g., huge developments in statistics). Nevertheless, it still seems that the concept of causality is at the core of explaining how the world works, across fields as diverse as physics, medicine, logistics, the law, sociology, and history – and ordinary daily life – through all of which, explanations and predictions in terms of cause and effect remain intuitively central.

Causality remains a thorny problem but, in recent decades, significant progress has occurred, particularly in work by or inspired by Judea Pearl. This work incorporates many 20th century developments, including statistical methods – but with a reemphasis on finding the why, or the cause, behind statistical correlations –, progress in understanding the logic, semantics and metaphysics of conditionals and counterfactuals, developments based on insights from the likes of philosopher Hans Reichenbach or biological statistician Sewall Wright into causal precedence and path analysis, and much more. The result is a new toolkit to identify causes and build causal explanations. Yet even as we get better at identifying causes, this raises new (or old) questions about causality, including metaphysical questions about the nature of causes (and effects, events, objects, etc), but also questions about what we really use causality for (understanding the world as it is or just to glean predictive control of specific outcomes), about how causality is used differently in different fields and activities (is cause in physics the same as that in history?), and about how other crucial concepts relate to our concept of cause (space and time seem to be related to causality, but so do concepts of legal and moral responsibility).

This course will introduce students to the mathematical formalism derived from Pearl's work, based on directed acyclic graphs and probability theory. Building upon previous work by Reichenbach and Wright, Pearl defines a "a calculus of interventions" of "do-calculus" for talking about interventions and their relation to causation and counterfactuals. This model has been applied in various areas ranging from econometrics to statistics, where acquiring knowledge about causality is of great importance.

At the same time, the course will not forget some of the metaphysical and epistemological issues around cause, so that students can better critically evaluate putative causal explanations in their full context. Abstractly, such issues involve some of the same philosophical questions Hume already asked, but more practically, it is important to see how metaphysical and epistemological debates surrounding the notion of cause affect scientific practice, and equally if not more importantly, how scientific practice pushes the limits of theory. This course will look at various ways in which empirical data can be transformed into explanations and theories, including the variance approach to causality (characteristic of the positivistic quantitative paradigm), and the process theory of causality (associated with qualitative methodology). Examples and case studies will be relevant for students of the social sciences but also students of the natural/physical world as well.

Intended Learning Outcomes

Students acquire transferable and key skills in this module.

By the end of this module, the students will be able to

1. have a clear understanding of the history of causal thinking.
2. be able to form a critical understanding of the key debates and controversies surrounding the idea of causality.
3. be able to recognize and apply probabilistic causal models.
4. be able to explain how understanding of causality differs among different disciplines.
5. be able demonstrate how theoretical thinking about causality has shaped scientific practices.

Indicative Literature

Paul, L. A. and Ned Hall. Causation: A User's Guide. Oxford University Press 2013.

Pearl, Judea. Causality: Models, Reasoning and Inference. Cambridge University Press 2009

Pearl, Judea, Glymour Madelyn and Jewell, Nicolas. Causal Inference in Statistics: A Primer. Wiley 2016

llari, Phyllis McKay and Federica Russo. Causality: Philosophical Theory Meets Scientific Practice. Oxford University Press 2014.

Usability and Relationship to other Modules

Examination Type: Module Examination

Assessment: Written examination

Duration/Length: 60 min

Weight: 100 %

Scope: All intended learning outcomes of the module

Completion: To pass this module, the examination has to be passed with at least 45%

8.2.5 Linear Model and Matrices

Module Name			Module Code	Level (type)	CP
Linear Model and Matrices			CTNS-NSK-05	Year 3 (New Skills)	5
Module Components					
Number	Name			Type	CP
CTNS-05	Linear models and Matrices			Seminar (online)	5
Module Coordinator Prof. Dr. Marc-Thorsten Hütt	**Program Affiliation** • CONSTRUCTOR Track Area			**Mandatory Status** Mandatory elective	
Entry Requirements Pre-requisites Logic Causation & Correlation	 Co-requisites ☒ none	 Knowledge, Abilities, or Skills •	**Frequency** Annually (Fall)	**Forms of Learning and Teaching** Online lecture (35h) Private Study (90h)	
			Duration 1 Semester	**Workload** 125 hours	

Recommendations for Preparation

Content and Educational Aims

There are no universal 'right skills'. But the notion of linear models and the avenue to matrices and their properties can be useful in diverse disciplines to implement a quantitative, computational approach. Some of the most popular data and systems analysis strategies are built upon this framework. Examples include principal component analysis (PCA), the optimization techniques used in Operations Research (OR), the assessment of stable and unstable states in nonlinear dynamical systems, as well as aspects of machine learning.

Here we introduce the toolbox of linear models and matrix-based methods embedded in a wide range of transdisciplinary applications (part 1). We describe its foundation in linear algebra (part 2) and the range of tools and methods derived from this conceptual framework (part 3). At the end of the course, we outline applications to graph theory and machine learning (part 4). Matrices can be useful representations of networks and of system of linear equations. They are also the core object of linear stability analysis, an approach used in nonlinear dynamics. Throughout the course, examples from neuroscience, social sciences, medicine, biology, physics, chemistry, and other fields are used to illustrate these methods.

A strong emphasis of the course is on the sensible usage of linear approaches in a nonlinear world. We will critically reflect the advantages as well as the disadvantages and limitations of this method. Guiding questions are: How appropriate is a linear approximation of a nonlinear system? What do you really learn from PCA? How reliable are the optimal states obtained via linear programming (LP) techniques?

This debate is embedded in a broader context: How does the choice of a mathematical technique confine your view on the system at hand? How, on the other hand, does it increase your capabilities of analyzing the system (due to software available for this technique, the ability to compare with findings from other fields built upon the same technique and the volume of knowledge about this technique)?

In the end, students will have a clearer understanding of linear models and matrix approaches in their own discipline, but they will also see the full transdisciplinarity of this topic. They will make better decisions in their choice of data analysis methods and become mindful of the challenges when going from a linear to a nonlinear thinking.

Intended Learning Outcomes

Upon completion of this module, students will be able to:

1. apply the concept of linear modeling in their own discipline
2. distinguish between linear and nonlinear interpretation strategies and understand the range of applicability of linear models
3. make use of data analysis / data interpretation strategies from other disciplines, which are derived from linear algebra
4. be aware of the ties that linear models have to machine learning and network theory

Note that these four ILOs can be loosely associated with the four parts of the course indicated above

Indicative Literature

Part 1:

material from Linear Algebra for Everyone, Gilbert Strang, Wellesley-Cambridge Press, 2020

Part 2:

material from Introduction to Linear Algebra (5th Edition), Gilbert Strang, Cambridge University Press, 2021

Part 3:

Mainzer, Klaus. "Introduction: from linear to nonlinear thinking." Thinking in Complexity: The Computational Dynamics of Matter, Mind and Mankind (2007): 1-16.

material from Mathematics of Big Data: Spreadsheets, Databases, Matrices, and Graphs, Jeremy Kepner, Hayden Jananthan, The MIT Press, 2018

material from Introduction to Linear Algebra (5th Edition), Gilbert Strang, Cambridge University Press, 2021

Part 4:

material from Linear Algebra and Learning from Data, Gilbert Strang, Wellesley-Cambridge Press, 2019

Usability and Relationship to other Modules

Examination Type: Module Examination

Assessment: Written examination Duration/Length: 120 min

Weight: 100 %

Scope: All intended learning outcomes of the module

Completion: To pass this module, the examination has to be passed with at least 45%

8.2.6 Complex Problem Solving

Module Name			**Module Code**	**Level (type)**	**CP**
Complex Problem Solving			CTNS-NSK-06	Year 3 (New Skills)	5
Module Components					
Number	Name			Type	CP
CTNS-06	Complex Problem Solving			Lecture (online)	5
Module Coordinator Marco Verweij	**Program Affiliation** • CONSTRUCTOR Track Area			**Mandatory Status** Mandatory elective	
Entry Requirements Pre-requisites Logic Causation & Correlation	Co-requisites ☒ none	Knowledge, Abilities, or Skills • Being able to read primary academic literature • Willingness to engage in teamwork	**Frequency** Annually (Fall)	**Forms of Learning and Teaching** Online Lectures (35h) Private Study (90h)	
			Duration 1 semester	**Workload** 125 hours	

Recommendations for Preparation

Please read: Camillus, J. (2008). Strategy as a wicked problem. Harvard Business Review 86: 99-106; Rogers, P. J. (2008). Using programme theory to evaluate complicated and complex aspects of interventions. Evaluation, 14, 29–48.

Content and Educational Aims

Complex problems are, by definition, non-linear and/or emergent. Some fifty years ago, scholars such as Herbert Simon began to argue that societies around the world had developed an impressive array of tools with which to solve simple and even complicated problems, but still needed to develop methods with which to address the rapidly increasing number of complex issues. Since then, a variety of such methods has emerged. These include 'serious games' developed in computer science, 'multisector systems analysis' applied in civil and environmental engineering, 'robust decision-making' proposed by the RAND Corporation, 'design thinking' developed in engineering and business studies, 'structured problem solving' used by McKinsey & Co., 'real-time technology assessment' advocated in science and technology studies, and 'deliberative decision-making' emanating from political science.

In this course, students first learn to distinguish between simple, complicated and complex problems. They also become familiar with the ways in which a particular issue can sometimes shift from one category into another. In addition, the participants learn to apply several tools for resolving complex problems. Finally, the students are introduced to the various ways in which natural and social scientists can help stakeholders resolve complex problems. Throughout the course examples and applications will be used. When possible, guest lectures will be offered by experts on a particular tool for tackling complex issues. For the written, take-home exam, students will have to select a specific complex problem, analyse it and come up with a recommendation – in addition to answering several questions about the material learned.

Intended Learning Outcomes

Upon completion of this module, students will be able to:

1. Identify a complex problem;
2. Develop an acceptable recommendation for resolving complex problems.
3. Understand the roles that natural and social scientists can play in helping stakeholders resolve complex problems;

Indicative Literature

Chia, A. (2019). Distilling the essence of the McKinsey way: The problem-solving cycle. Management Teaching Review 4(4): 350-377.

Den Haan, J., van der Voort, M.C., Baart, F., Berends, K.D., van den Berg, M.C., Straatsma, M.W., Geenen, A.J.P., & Hulscher, S.J.M.H. (2020). The virtual river game: Gaming using models to collaboratively explore river management complexity, Environmental Modelling & Software 134, 104855,

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C.S., & Walker, B. (2002). Resilience and sustainable development: Building adaptive capacity in a world of transformations. AMBIO: A Journal of the Human Environment 31(5): 437-440.

Ostrom, E. (2010). Beyond markets and states: Polycentric governance of complex economic systems. American Economic Review 100(3): 641-72.

Pielke, R. Jr. (2007). The honest broker: Making sense of science in policy and politics. Cambridge: Cambridge University Press.

Project Management Institute (2021). A guide to the project management body of knowledge (PMBOK® guide).

Schon, D. A., & Rein, M. (1994). Frame reflection: Toward the resolution of intractable policy controversies. New York: Basic Books.

Simon, H. A. (1973). The structure of ill structured problems. Artificial Intelligence 4(3-4): 181-201.

Verweij, M. & Thompson, M. (Eds.) (2006). Clumsy solutions for a complex world. London: Palgrave Macmillan.

Usability and Relationship to other Modules

Examination Type: Module Examination

Assessment Type: Written examination Duration: 120 min

Weight: 100%

Scope: All intended learning outcomes of the module.

Completion: To pass this module, the examination has to be passed with at least 45%

8.2.7 Argumentation, Data Visualization and Communication (perspective I)

Module Name		Module Code	Level (type)	CP
Argumentation, Data Visualization and Communication (perspective I)		CTNS-NSK-07	Year 3 (New Skills)	5
Module Components				
Number	Name		Type	CP
CTNS-07	Argumentation, Data Visualization and Communication (perspective I)		Lecture (online)	5
Module Coordinator Prof. Dr. Jules Coleman, Prof Dr. Arvid Kappas	**Program Affiliation** • CONSTRUCTOR Track Area		**Mandatory Status** Mandatory elective for all UG students (one perspective must be chosen)	
Entry Requirements Pre-requisites Logic Causation & Correlation	Co-requisites ☒ none	Knowledge, Abilities, or Skills	**Frequency** Annually (Fall)	**Forms of Learning and Teaching** Online Lectures (35h) Private Study (90h)
			Duration 1 semester	**Workload** 125h
Recommendations for Preparation				

One must be careful not to confuse argumentation with being argumentative. The latter is an unattractive personal attribute, whereas the former is a requirement of publicly holding a belief, asserting the truth of a proposition, the plausibility of a hypothesis, or a judgment of the value of a person or an asset. It is an essential component of public discourse. Public discourse is governed by norms and one of those norms is that those who assert the truth of a proposition or the validity of an argument or the responsibility of another for wrongdoing open themselves up to good faith requests to defend their claims. In its most general meaning, argumentation is the requirement that one offer evidence in support of the claims they make, as well as in defense of the judgments and assessments they reach. There are different modalities of argumentation associated with different contexts and disciplines. Legal arguments have a structure of their own as do assessments of medical conditions and moral character. In each case, there are differences in the kind of evidence that is thought relevant and, more importantly, in the standards of assessment for whether a case has been successfully made. Different modalities of argumentation require can call for different modes of reasoning. We not only offer reasons in defense of or in support of beliefs we have, judgments we make and hypotheses we offer, but we reason from evidence we collect to conclusions that are warranted by them.

Reasoning can be informal and sometimes even appear unstructured. When we recognize some reasoning as unstructured yet appropriate what we usually have in mind is that it is not linear. Most reasoning we are familiar with is linear in character. From A we infer B, and from A and B we infer C, which all together support our commitment to D. The same form of reasoning applies whether the evidence for A, B or C is direct or circumstantial. What changes in these cases is perhaps the weight we give to the evidence and thus the confidence we have in drawing inferences from it.

Especially in cases where reasoning can be supported by quantitative data, wherever quantitative data can be obtained either directly or by linear or nonlinear models, the visualization of the corresponding data can become key in both, reasoning and argumentation. A graphical representation can reduce the complexity of argumentation and is considered a must in effective scientific communication. Consequently, the course will also focus on smart and compelling ways for data visualization - in ways that go beyond what is typically taught in statistics or mathematics lectures. These tools are constantly developing, as a reflection of new software and changes in state of the presentation art. Which graph or bar chart to use best for which data, the use of colors to underline messages and arguments, but also the pitfalls when presenting data in a poor or even misleading manner. This will also help in readily identifying intentional mis-representation of data by others, the simplest to recognize being truncating the ordinate of a graph in order to exaggerate trends. This frequently leads to false arguments, which can then be readily countered.

There are other modalities of reasoning that are not linear however. Instead they are coherentist. We argue for the plausibility of a claim sometimes by showing that it fits in with a set of other claims for which we have independent support. The fit is itself the reason that is supposed to provide confidence or grounds for believing the contested claim.

Other times, the nature of reasoning involves establishing not just the fit but the mutual support individual items in the evidentiary set provide for one another. This is the familiar idea of a web of interconnected, mutually supportive beliefs. In some cases, the support is in all instances strong; in others it is uniformly weak, but the set is very large; in other cases, the support provided each bit of evidence for the other is mixed: sometimes strong, sometimes weak, and so on.

There are three fundamental ideas that we want to extract from this segment of the course. These are (1) that argumentation is itself a requirement of being a researcher who claims to have made findings of one sort or another; (2) that there are different forms of appropriate argumentation for different domains and circumstances; and (3) that there are different forms of reasoning on behalf of various claims or from various bits of evidence to conclusions: whether those conclusions are value judgments, political beliefs, or scientific conclusions. Our goal is to familiarize you with all three of these deep ideas and to help you gain facility with each.

Intended Learning Outcomes

Students acquire transferable and key skills in this module.

By the end of this module, the students will be able to

1. Distinguish among different modalities of argument, e.g. legal arguments, vs. scientific ones.
2. Construct arguments using tools of data visualization.
3. Communicate conclusions and arguments concisely, clearly and convincingly.

Indicative Literature

- Tufte, E.R. (1985). The visual display of quantitative information. The Journal for Healthcare Quality (JHQ), 7(3), 15.
- Cairo, A (2012). The Functional Art: An introduction to information graphics and visualization. New Ridders.
- Knaflic, C.N. (2015). Storytelling with data: A data visualization guide for business professionals. John Wiley & Sons.

Usability and Relationship to other Modules

Examination Type: Module Examination

Assessment Type: Written Examination

Duration: 120 (min)
Weight: 100%

Scope: All intended learning outcomes of the module

Completion: To pass this module, the examination has to be passed with at least 45%

8.2.8 Argumentation, Data Visualization and Communication (perspective II)

<table>
<tr><td colspan="2">Module Name

Argumentation, Data Visualization and Communication (perspective II)</td><td>Module Code
CTNS-NSK-08</td><td>Level (type)
Year 3
(New Skills)</td><td>CP
5</td></tr>
<tr><td colspan="5">Module Components</td></tr>
<tr><td>Number</td><td colspan="2">Name</td><td>Type</td><td>CP</td></tr>
<tr><td>CTNS-08</td><td colspan="2">Argumentation, Data Visualization and Communication (perspective II)</td><td>Lecture (online)</td><td>5</td></tr>
<tr><td>Module Coordinator

Prof. Dr. Jules Coleman,
Prof Dr. Arvid Kappas</td><td colspan="2">Program Affiliation

• CONSTRUCTOR Track Area</td><td colspan="2">Mandatory Status

Mandatory elective for all UG students (one perspective must be chosen)</td></tr>
<tr><td colspan="2">Entry Requirements

Pre-requisites: Logic; Causation & Correlation
Co-requisites: ☒ none
Knowledge, Abilities, or Skills:
• ability and openness to engage in interactions
• media literacy, critical thinking and a proficient handling of data sources
• own research in academic literature</td><td>Frequency

Annually (Spring)

Duration

1 semester</td><td colspan="2">Forms of Learning and Teaching

• Online Lecture (35 hours)
• Tutorial of the lecture (10 hours)
• Private study for the lecture (80 hours)

Workload

125 hours</td></tr>
<tr><td colspan="5">Recommendations for Preparation</td></tr>
<tr><td colspan="5">Content and Educational Aims
Humans are a social species and interaction is crucial throughout the entire life span. While much of human communication involves language, there is a complex multichannel system of nonverbal communication that enriches linguistic content, provides context, and is also involved in structuring dynamic interaction. Interactants achieve goals by encoding information that is interpreted in the light of current context in transactions with others. This complexity implies also that there are frequent misunderstandings as a sender’s intention is not fulfilled. Students in this course will learn to understand the structure of communication processes in a variety of formal and informal contexts. They will learn what constitutes challenges to achieving successful communication and to how to communicate effectively, taking the context and specific requirements for a target audience into consideration. These aspects will be discussed also in the scientific context, as well as business, and special cases, such as legal context – particularly with view to argumentation theory.

Communication is a truly transdisciplinary concept that involves knowledge from diverse fields such as biology, psychology, neuroscience, linguistics, sociology, philosophy, communication and information science. Students will learn what these different disciplines contribute to an understanding of communication and how theories from these fields can be applied in the real world. In the context of scientific communication, there will also be a focus on visual communication of data in different disciplines. Good practice examples will be contrasted with typical errors to facilitate successful communication also with view to the Bachelor’s thesis.</td></tr>
</table>

Intended Learning Outcomes

Upon completion of this module, students will be able to

1. Analyze communication processes in formal and informal contexts.
2. Identify challenges and failures in communication.
3. Design communications to achieve specified goals to specific target groups.
4. Understand the principles of argumentation theory.
5. Use data visualization in scientific communications.

Indicative Literature

- Joseph A. DeVito: The Interpersonal Communication Book (Global edition, 16th edition), 2022
- Steven L. Franconeri, Lace M. Padilla, Priti Shah, Jeffrey M. Zacks, and Jessica Hullman: The Science of Visual Data Communication: What Works Psychological Science in the Public Interest, 22(3), 110–161, 2022
- Douglas Walton: Argumentation Theory – A Very Short Introduction. In: Simari, G., Rahwan, I. (eds) Argumentation in Artificial Intelligence. Springer, Boston, MA, 2009

Examination Type: Module Examination

Assessment Type: Digital submission of asynchronous presentation, including reflection

Duration/Length: Asynchronous/Digital submission

Weight: 100%

Scope: All intended learning outcomes of the module

Module achievement: Asynchronous presentation on a topic relating to the major of the student, including a reflection including concept outlining the rationale for how arguments are selected and presented based on a particular target group for a particular purpose. The presentation shall be multimedial and include the presentation of data

The module achievement ensures sufficient knowledge about key concepts of effective communication including a reflection on the presentation itself

Completion: To pass this module, the examination has to be passed with at least 45%.

8.2.9 Agency, Leadership, and Accountability

<table>
<tr><td colspan="3">Module Name
Agency, Leadership, and Accountability</td><td>Module Code
CTNS-NSK-09</td><td>Level (type)
Year 3
(New Skills)</td><td>CP
5</td></tr>
<tr><td colspan="6">Module Components</td></tr>
<tr><td>Number</td><td colspan="3">Name</td><td>Type</td><td>CP</td></tr>
<tr><td>CTNS-09</td><td colspan="3">Agency, Leadership, and Accountability</td><td>Lecture (online)</td><td>5</td></tr>
<tr><td>Module Coordinator

Prof. Dr. Jules Coleman</td><td colspan="3">Program Affiliation
CONSTRUCTOR Track Area</td><td colspan="2">Mandatory Status

Mandatory for CSSE
Mandatory elective for all other UG study programs</td></tr>
<tr><td colspan="3" rowspan="2">Entry Requirements

Pre-requisites: ☒ none
Co-requisites: ☒ none
Knowledge, Abilities, or Skills</td><td>Frequency

Annually
(Spring)</td><td colspan="2">Forms of Learning and Teaching

Online Lectures (35h)
Private Study (90h)</td></tr>
<tr><td>Duration
1 semester</td><td colspan="2">Workload

125 hours</td></tr>
<tr><td colspan="6">Recommendations for Preparation</td></tr>
<tr><td colspan="6">Content and Educational Aims</td></tr>
</table>

Each of us is judged by the actions we undertake and held to account for the consequences of them. Sometimes we may be lucky and our bad acts don't have harmful effects on others. Other times we may be unlucky and reasonable decisions can lead to unexpected or unforeseen adverse consequences for others. We are therefore held accountable both for choices and for outcomes. In either case, accountability expresses the judgment that we bear responsibility for what we do and what happens as a result. But our responsibility and our accountability in these cases is closely connected to the idea that we have agency.

Agency presumes that we are the source of the choices we make and the actions that result from those choices. For some, this may entail the idea that we have free will. But there is scientific world view that holds that all actions are determined by the causes that explain them, which is the idea that if we knew the causes of your decisions in advance, we would know the decision you would make even before you made it. If that is so, how can your choice be free? And if it is not free, how can you be responsible for it? And if you cannot be responsible, how can we justifiably hold you to account for it?

These questions express the centuries old questions about the relationship between free will and a determinist world view: for some, the conflict between a scientific world view and a moral world view.

But we do not always act as individuals. In society we organize ourselves into groups: e.g. tightly organized social groups, loosely organized market economies, political societies, companies, and more. These groups have structure. Some individuals are given the responsibility of leading the group and of exercising authority. But one can exercise authority over others in a group merely by giving orders and threatening punishment for non-compliance.

Exercising authority is not the same thing as being a leader? For one can lead by example or by encouraging others to exercise personal judgment and authority. What then is the essence of leadership?

The module has several educational goals. The first is for students to understand the difference between actions that we undertake for which we can reasonably held accountable and things that we do but which we are not responsible for. For example, a twitch is an example of the latter, but so too may be a car accident we cause as a result of a heart attack we had no way of anticipating or controlling. This suggests the importance of control to responsibility. At the heart of personal agency is the idea of control. The second goal is for students to understand what having control means. Some think that the scientific view is that the world is deterministic, and if it is then we cannot have any personal control over what happens, including what we do. Others think that the quantum scientific view entails a degree of indeterminacy and that free will and control are possible, but only in the sense of being unpredictable or random. But then random outcomes are not ones we control either. So, we will devote most attention to trying to understand the relationships between control, causation and predictability.

But we do not only exercise agency in isolation. Sometimes we act as part of groups and organizations. The law often recognizes ways in which groups and organizations can have rights, but is there a way in which we can understand how groups have responsibility for outcomes that they should be accountable for. We need to figure out then whether there is a notion of group agency that does not simply boil down to the sum of individual actions. We will explore the ways in which individual actions lead to collective agency.

Finally we will explore the ways in which occupying a leadership role can make one accountable for the actions of others over which one has authority.

Intended Learning Outcomes

Students acquire transferable and key skills in this module.

By the end of this module, the students will be able to

1. Understand and reflect how the social and moral world views that rely on agency and responsibility are compatible, if they are, with current scientific world views.
2. understand how science is an economic sector, populated by large powerful organizations that set norms and fund research agendas.
3. identify the difference between being a leader of others or of a group – whether a research group or a lab or a company – and being in charge of the group.
4. learn to be a leader of others and groups. Understand that when one graduates one will enter not just a field of work but a heavily structured set of institutions and that one's agency and responsibility for what happens, what work gets done, its quality and value, will be affected accordingly.

Indicative Literature

Hull, David L. "Science as a Process." Science as a Process. University of Chicago Press, 2010;

Feinberg, Joel. "Doing & deserving; essays in the theory of responsibility." (1970).

Usability and Relationship to other Modules

Examination Type: Module Examination

Assessment Type: Written examination

Duration/Length: 120 min
Weight: 100%

Scope: All intended learning outcomes of the module

Completion: To pass this module, the examination has to be passed with at least 45%

8.2.10 Community Impact Project

Module Name			Module Code	Level (type)	CP
Community Impact Project			CTNC-CIP-10	Year 3 (New Skills)	5
Module Components					
Number	Name			Type	CP
CTNC-10	Community Impact Project			Project	5
Module Coordinator	**Program Affiliation**			**Mandatory Status**	
CIP Faculty Coordinator	• CONSTRUCTOR Track Area			Mandatory elective	
Entry Requirements			**Frequency**	**Forms of Learning and Teaching**	
Pre-requisites	Co-requisites	Knowledge, Abilities, or Skills	Annually (Fall / Spring)	• Introductory, accompanying, and final events: 10 hours • Self-organized teamwork and/or practical work in the community: 115 hours	
☒ at least 15 CP from CORE modules in the major	☒ None	• Basic knowledge of the main concepts and methodological instruments of the respective disciplines	**Duration**	**Workload**	
			1 semester	125 hours	

Recommendations for Preparation

Develop or join a community impact project before the 5th or 6th semester based on the introductory events during the 4th semester by using the database of projects, communicating with fellow students and faculty, and finding potential companies, organizations, or communities to target.

Content and Educational Aims

CIPs are self-organized, major-related, and problem-centered applications of students' acquired knowledge and skills. These activities will ideally be connected to their majors so that they will challenge the students' sense of practical relevance and social responsibility within the field of their studies. Projects will tackle real issues in their direct and/or broader social environment. These projects ideally connect the campus community to other communities, companies, or organizations in a mutually beneficial way.
Students are encouraged to create their own projects and find partners (e.g., companies, schools, NGOs), but will get help from the CIP faculty coordinator team and faculty mentors to do so. They can join and collaborate in interdisciplinary groups that attack a given issue from different disciplinary perspectives.
Student activities are self-organized but can draw on the support and guidance of both faculty and the CIP faculty coordinator team.

Intended Learning Outcomes

The Community Impact Project is designed to convey the required personal and social competencies for enabling students to finish their studies at Constructor University as socially conscious and responsible graduates (part of the Constructor University's mission) and to convey social and personal abilities to the students, including a practical awareness of the societal context and relevance of their academic discipline.

By the end of this project, students will be able to

1. understand the real-life issues of communities, organizations, and industries and relate them to concepts in their own discipline;
2. enhance problem-solving skills and develop critical faculty, create solutions to problems, and communicate these solutions appropriately to their audience;
3. apply media and communication skills in diverse and non-peer social contexts;

4. develop an awareness of the societal relevance of their own scientific actions and a sense of social responsibility for their social surroundings;
5. reflect on their own behavior critically in relation to social expectations and consequences;
6. work in a team and deal with diversity, develop cooperation and conflict skills, and strengthen their empathy and tolerance for ambiguity.

Indicative Literature

Not specified

Usability and Relationship to other Modules

- Students who have accomplished their CIP (6th semester) are encouraged to support their fellow students during the development phase of the next year's projects (4th semester).

Examination Type: Module Examination

Project, not numerically graded (pass/fail)
Scope: All intended learning outcomes of the module

8.3 Language and Humanities Modules

8.3.1 Languages

The descriptions of the language modules are provided in a separate document, the “Language Module Handbook” that can be accessed from the Constructor University’s Language & Community Center internet sites (https://constructor.university/student-life/language-community-center/learning-languages).

8.3.2 Humanities

8.3.2.1 Introduction into Philosophical Ethics

Module Name			Module Code	Level (type)	CP
Introduction to Philosophical Ethics			CTHU-HUM-001	Year 1	2.5
Module Components					
Number	Name			Type	CP
CTHU-001	Introduction to Philosophical Ethics			Lecture (online)	2.5
Module Coordinator Dr. Eoin Ryan	**Program Affiliation** • CONSTRUCTOR Track Area			**Mandatory Status** Mandatory elective	
Entry Requirements			**Frequency** Annually (Fall)	**Forms of Learning and Teaching** Online lectures (17.5 h) Private Study (45h)	
Pre-requisites ☒ none	Co-requisites ☒ none	Knowledge, Abilities, or Skills •	**Duration** 1 semester	**Workload** 62.5 hours	
Recommendations for Preparation					
Content and Educational Aims					
The nature of morality – how to lead a life that is good for yourself, and how to be good towards others – has been a central debate in philosophy since the time of Socrates, and it is a topic that continues to be vigorously discussed. This course will introduce students to some of the key aspects of philosophical ethics, including leading normative theories of ethics (e.g. consequentialism or utilitarianism, deontology, virtue ethics, natural law ethics, egoism) as well as some important questions from metaethics (are useful and generalizable ethical claims even possible; what do ethical speech and ethical judgements actually do or explain) and moral psychology (how do abstract ethical principles do when realized by human psychologies). The course will describe ideas that are key factors in ethics (free will, happiness, responsibility, good, evil, religion, rights) and indicate various routes to progress in understanding ethics, as well as some of their difficulties.					

Intended Learning Outcomes

Upon completion of this module, students will be able to

1. Describe normative ethical theories such as consequentialism, deontology and virtue ethics.
2. Discuss some metaethical concerns.
3. Analyze ethical language.
4. Highlight complexities and contradictions in typical ethical commitments.
5. Indicate common parameters for ethical discussions at individual and social levels.
6. Analyze notions such as objectivity, subjectivity, universality, pluralism, value.

Indicative Literature

Simon Blackburn, Being Good (2009)

Russ Shafer-Landay, A Concise Introduction to Ethics (2019)

Mark van Roojen, Metaethicas: A Contemporary Introduction (2015)

Usability and Relationship to other Modules

Examination Type: Module Examination

Assessment Type: Written Examination

Duration/Length: 60 min
Weight: 100%

Scope: All intended learning outcomes of the module.

Completion: To pass this module, the examination has to be passed with at least 45%

8.3.2.2 Introduction to the Philosophy of Science

Module Name Introduction to the Philosophy of Science			**Module Code** CTHU-HUM-002	**Level (type)** Year 1	**CP** 2.5
Module Components					
Number	Name			Type	CP
CTHU-002	Introduction to the Philosophy of Science			Lecture (online)	2.5
Module Coordinator Dr. Eoin Ryan	**Program Affiliation** • CONSTRUCTOR Track Area			**Mandatory Status** Mandatory elective	
Entry Requirements			**Frequency** Annually (Spring)	**Forms of Learning and Teaching** Online lectures (17.5h) Private Study (45h)	
Pre-requisites ☒ none	Co-requisites ☒ none	Knowledge, Abilities, or Skills	**Duration** 1 semester	**Workload** 62.5 hours	
Recommendations for Preparation					
Content and Educational Aims This humanities module will introduce students to some of the central ideas in philosophy of science. Topics will include distinguishing science from pseudo-science, types of inference and the problem of induction, the pros and cons of realism and anti-realism, the role of explanation, the nature of scientific change, the difference between natural and social sciences, scientism and the values of science, as well as some examples from philosophy of the special sciences (e.g., physics, biology). The course aims to give students an understanding of how science produces knowledge, and some of the various contexts and issues which mean this process is never entirely transparent, neutral, or unproblematic. Students will gain a critical understanding of science as a human practice and technology; this will enable them both to better understand the importance and success of science, but also how to properly critique science when appropriate.					
Intended Learning Outcomes Upon completion of this module, students will be able to 1. Understand key ideas from the philosophy of science. 2. Discuss different types of inference and rational processes. 3. Describe differences between how the natural sciences, social sciences and humanities discover knowledge. 4. Identify ways in which science can be more and less value-laden. 5. Illustrate some important conceptual leaps in the history of science.					
Indicative Literature Peter Godfrey-Smith, Theory and Reality (2021) James Ladyman, Understanding Philosophy of Science (2002) Paul Song, Philosophy of Science: Perspectives from Scientists (2022)					
Usability and Relationship to other Modules					

Examination Type: Module Examination Assessment Type: Written Examination — Duration/Length: 60 min Weight: 100% Scope: All intended learning outcomes of the module. Completion: To pass this module, the examination has to be passed with at least 45%

8.3.2.3 Introduction to Visual Culture

Module Name			Module Code	Level (type)	CP
Introduction to Visual Culture			CTHU-HUM-003	Year 1	2.5
Module Components					
Number	Name			Type	CP
CTHU-003	Introduction to Visual Culture			Lecture (online)	2.5
Module Coordinator Irina Chiaburu	**Program Affiliation** • CONSTRUCTOR Track Area			**Mandatory Status** Mandatory elective	
Entry Requirements			**Frequency** Annually (Spring/Fall)	**Forms of Learning and Teaching** Online Lecture	
Pre-requisites	Co-requisites	Knowledge, Abilities, or Skills			
☒ none	☒ none	•	**Duration** 1 semester	**Workload** 62.5 h	

Recommendations for Preparation

Content and Educational Aims

Of the five senses, the sense of sight has for a long time occupied the central position in human cultures. As John Berger has suggested this could be because we can see and recognize the world around us before we learn how to speak. Images have been with us since the earliest days of the human history. In fact, the earliest records of human history are images found on cave walls across the world. We use images to capture abstract ideas, to catalogue and organize the world, to represent the world, to capture specific moments, to trace time and change, to tell stories, to express feelings, to better understand, to provide evidence and more. At the same time, images exert their power on us, seducing us into believing in their 'innocence', that is into forgetting that as representations they are also interpretations, i.e., a particular version of the world.

The purpose of this course is to explore multiple ways in which images and the visual in general mediate and structure human experiences and practices from more specialized discourses, e.g., scientific discourses, to more informal and personal day-to-day practices, such as self-fashioning in cyberspace. We will look at how social and historical contexts affect how we see, as well as what is visible and what is not. We will explore the centrality of the visual to the intellectual activity, from early genres of scientific drawing to visualizations of big data. We will examine whether one can speak of visual culture of protest, look at the relationship between looking and subjectivity and, most importantly, ponder the relationship between the visual and the real.

Intended Learning Outcomes

Upon completion of this module, students will be able to

1. Understand a range of key concepts pertaining to visual culture, art theory and cultural analysis
2. Understand the role visuality plays in development and maintenance of political, social, and intellectual discourses
3. Think critically about images and their contexts
4. Reflect critically on the connection between seeing and knowing

Indicative Literature

Berger, J., Blomberg, S., Fox, C., Dibb, M., & Hollis, R. (1973). Ways of seeing.
Foucault, M. (2002). The order of things: an archaeology of the human sciences (Ser. Routledge classics). Routledge.
Hunt, L. (2004). Politics, culture, and class in the French revolution: twentieth anniversary edition, with a new preface (Ser. Studies on the history of society and culture, 1). University of California Press.
Miller, V. (2020). Understanding digital culture (Second). SAGE.
Thomas, N. (1994). Colonialism's culture: anthropology, travel and government. Polity Press.

Usability and Relationship to other Modules

Examination Type: Module Examination

Assessment: Written examination Duration/Length: 60 min.

Weight: 100%

Scope: all intended learning outcomes

Completion: To pass this module, the examination has to be passed with at least 45%

9 Appendix

9.1 Intended Learning Outcomes Assessment Matrix

Physics and Data Science (PHDS)					Classical Physics	Programming in Python and C++	Modern Physics	Mathematical Modeling	Core Algorithms and Data Structures	Algorithms and Data Structures	Analytical Mechanics	Electrodynamics & Relativity	Quantum Mechanics	Statistical Physics	Advanced Physics Lab I	Advanced Physics Lab II	Computational Modeling	Scientific Data Analysis	Machine Learning	Specialization modules	Bachelor Thesis and Seminar	Internship	CT Methods	CT New Skills	CT Language / Humanities
Semester					1	1	2	2	2	2	3	3	4	4	3	4	3-4	3	4	5-6	6	5	1-4	3-6	1-2
Mandatory/mandatory elective					m	m	m	m	me	me	m	m	m	m	m	m	m	m	m	me	m	m	m	m	m
Credits					7.5	7.5	7.5	7.5	7.5	7.5	5	5	5	5	5	5	5	5	5	5	15	15	20	20	10
	Competencies*																								
Program Learning Outcomes	**A**	**E**	**P**	**S**																					
recall and understand the basic facts, principles, formulas, and experimental evidence from the major fields of physics, namely, classical physics, modern physics, and statistical physics;	x				x		x				x	x	x	x	x	x				x					
describe and understand natural and technical phenomena by reducing them to basic physical principles from the various fields of physics;	x	x			x		x				x	x	x	x						x					
analyze complex systems to extract underlying and organizing principles;	x	x		x				x										x	x						
use programming skills to build and assess data-based models;	x	x				x			x	x							x	x							
apply a variety of mathematical methods and tools especially from analysis and linear algebra to describe physical systems;	x	x									x	x	x	x	x	x				x			x		
use numerical and computational methods to describe and analyze physical systems;	x	x															x	x					(x)		
design and apply data management tools, including the case of large datasets;	x	x				x			x	x								x							
examine physical problems and apply their mathematical skills and knowledge from different fields in physics to find possible solutions and assess them critically;	x	x			x		x	x			x	x	x	x	x	x				x	x				
conceive and apply analogies, approximations, estimates, or extreme cases to test the plausibility of ideas or solution to physical problems;	x	x						x			x	x	x	x						x	x				
set up and perform experiments, analyze their outcomes with the pertinent precision, and present them properly;	x	x			x		x								x	x					(x)				
proficiently perform advanced statistical data analysis and apply artificial intelligence tools for data processing;	x	x		x														x	x				(x)		
work responsibly in a team on a common task, with the necessary preparation, planning, communication, and work organization;	x	x	x	x	x		x								x	x	x			(x)	(x)			x	
use the appropriate language of the scientific community to communicate, discuss, and defend scientific findings and ideas in physics;	x	x	x												x	x				x	x	x	x		
familiarize themselves with a new field in physics by finding, reviewing, and digesting the relevant scientific information to work independently or as a team member on a physics-related problem or on a scientific research project;			x												x	x				x	x	x			
apply their knowledge and understanding from their BSc Physics and Data Science education to advance their personal career either by professional employment or by further academic or professional education;			x																		x	x			x
take on responsibility for their own personal and professional role in society by critical self-evaluation and self-analysis;				x																	x	x		x	(x)
adhere to and defend ethical, scientific, and professional standards, but also reflect on and respect different views;				x																				x	x
act as a scientifically literate citizen to provide sound evidence-based solutions and arguments especially when communicating with specialists or laymen, or when dealing with technology or science issues;				x																				x	(x)
appreciate the importance of education, community, and diversity for personal development and a peaceful and sustainable world.			x	x																		x		x	(x)
Assessment Type																									
Oral examination															x	x									
Final written exam					x	x	x	x	x	x	x	x	x	x					x	x			x	x	x
Project																	x			x					
Essay																									
(Lab) report					x		x								x	x				x	(x)				
Poster presentation																									
Presentation																				x	x			x	
Portfolio																		x		x					
other						x		x	x													x			x
Thesis																					x				
Module achievements/bonus achievements					x		x				x	x	x	x											

*Competencies: A-scientific/academic proficiency; E-competence for qualified employment; P-development of personality; S-competence for engagement in society

Figure 4: Intended Learning Outcomes Assessment-Matrix