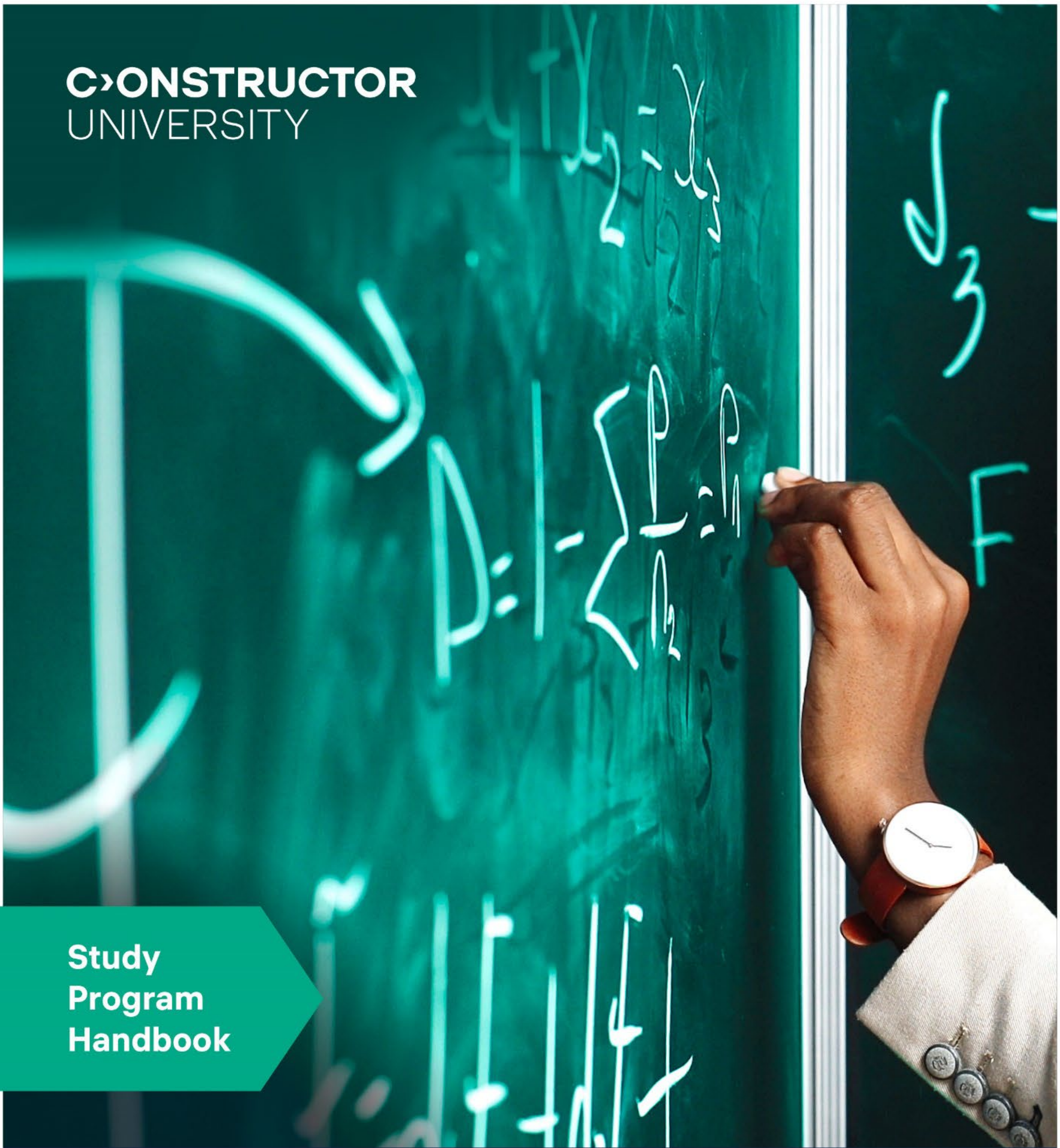
CONSTRUCTOR UNIVERSITY



Study Program Handbook

Mathematics, Modeling and Data Analytics

Bachelor of Science

Subject-specific Examination Regulations for Mathematics, Modeling and Data Analytics (Fachspezifische Prüfungsordnung)

The subject-specific examination regulations for Mathematics, Modeling and Data Analytics 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		Apr 29, 2025	Editorial changes in Qualification Aims
Fall 2023-V1.3		Sep, 18, 2023	Editorial changes in the study and scheme plan
Fall 2023-V1.2		Aug 02, 2023	Editorial changes in all study schemes
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Fall 2023 – V1	Sep 01, 2023	Apr 26, 2023	Substantial change approved by the Academic Senate
		June 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 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 in 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

Mathematics is at the foundation of science, ranging from the beauty of theory and pure thought to applications in almost all areas of the natural sciences, engineering, economics, finance, and even the social sciences. While Mathematics is an ancient subject, and its applications also date back to many centuries, recent advances of the last two decades in Data Science have revolutionzed all these applications as well as some areas of mathematics itself.

As such, a bachelor's degree in Mathematics, Modeling and Data Analytics offers a unique combination of intellectual breadth and disciplinary depth. Specifically,

- Mathematics, Modeling and Data Analytics offers a great variety of academic career paths, ranging from teaching at all levels to research in mathematics and its adjacent fields, as well as all careers where Data analytics is valuable.
- a bachelor's degree in Mathematics, Modeling and Data Analytics qualifies students for graduate study not only in Mathematics, but also in neighboring disciplines such as Engineering, Physics, Data Science, Economics, Finance, MBA programs, and many others;
- Mathematical thinking combined with modeling and programming skills is the key to employment in a variety of high-level strategic positions in which analytic thinking, problem solving, and quantitative skills are paramount, ranging from consultancy, public administration, information technology, and data security, to high-level management.

In surveys, mathematicians consistently report strong personal identification with their field in combination with a high level of job satisfaction.

1.2 Specific Advantages of Mathematics, Modeling and Data Analytics at Constructor University

The key element in our education is that we do not simply teach courses to students but accompany them as individuals throughout their education and help them identify, or even achieve, their personal goals. In this spirit, the Bachelor Program in Mathematics, Modeling and Data Analytics at Constructor University offers

- a three-year program with advanced study options providing optimal preparation for graduate education at top European and US universities,
- a flexible curriculum which adapts to student interests and pace a flexible choice of a minor subject,
- small classes and close faculty-student interaction,
- personal mentoring and advising,
- options for early involvement in research,
- vibrant international community of motivated and gifted peers.

A key advantage of this interdisciplinary program is that it equips students both with mathematical tools for formulating and analyzing problems as well as context provided in modeling real-world problems and algorithmic data-driven approaches towards solving them. The strong mathematical foundation sought for in the program equips students with more powerful methods of analysis and modeling problems serves as a wide source of mathematical questions.

1.3 Program-Specific Educational Aims

1.3.1 Qualification Aims

The program aims at a broad general education in mathematical and modeling skills, where a high level of mathematical thinking and modeling skills is brought to bear on dealing with many challenging problems emerging from contemporary applied contexts. The program is designed with the goal in mind that its graduates are optimally qualified to continue graduate education in pure or applied mathematics or in a variety of fields of application. At the same time, the program aims at developing key transferable skills for a future professional career, either indirectly via a graduate degree or by direct entry into the work force with a bachelor's degree in Mathematics, Modeling and Data Analytics.

The detailed overarching program aims are

- comprehensive basic education in the core fields of pure and applied mathematics;
- Comprehensive skills in solving mathematical modeling problems and their implementation
- Basic education in data analytics and its application to modeling problems;
- optionally teach the core principles of scientific computing and/or financial mathematics;
- provide the option to achieve additional depth in the core areas of mathematics via a flexible choice of specialization modules and possible early entrainment into research
- lead students into taking responsibility for themselves, for others, and for society at large, and to responding constructively and effectively to new and important challenges.

1.3.2 Intended Learning Outcomes

By the end of the program, students will possess a wide range of skills in Mathematics, Modeling and Data Analytics. They will be able to

1. make rigorous mathematical arguments and understand the concept of mathematical proof;
2. recognize patterns and discover underlying principles;
3. confidently apply the methods in the core fields of pure and applied mathematics (Analysis, Linear Algebra, Numerical Analysis, Probability, Topology, Geometry) at a level allowing easy transition into top graduate schools around the world;
4. Create mathematical models for a wide range of real-world problems;
5. Perform statistical analysis, machine learning algorithms, and visualize data;
6. Solve mathematical problems, independently analyze mathematical proofs, and present them coherently;
7. understand and be able to apply the key concepts in two or more of the following, at the level of a first advanced undergraduate course: Complex Analysis, Algebra, Ordinary Differential Equations, Number Theory, Stochastic Processes, Dynamical Systems and Discrete Mathematics.

Graduates possess the following Practical Skills:

8. the ability to write programs in at least one programming language;
9. Knowledge in mathematical modeling and their application to everyday problems;
10. Ability to formulate mathematical ideas in written text;
11. Ability to present mathematical ideas to others.

Further, graduates possess the following Transferable Skills. They are able to

12. think analytically;

13. present complex ideas to specialists and non-specialists;
14. are confident in acquiring, understanding, and organizing information;
15. possess generic problem-solving skills, including a sense of determining what is already known, what is not known, and what is required to obtain a solution;
16. demonstrate a sense for the use of Mathematics in one or more fields of application.

Finally, graduates possess the following Subject-independent Skills. They are able to

17. engage ethically with academic and professional communities, and with the general public to actively contribute to a sustainable future, reflecting and respecting different views;
18. take responsibility for their own learning, personal and professional development and role in society, evaluating critical feedback and self-analysis;
19. take on responsibility in a diverse team;
20. adhere to and defend ethical, scientific and professional standards.

1.4 Career Options

A degree in Mathematics, Modeling and Data Analytics opens the door for a wide range of career options. These include:

- Insurance companies hire mathematicians in actuarial and other analyst positions.
- Quantitative Finance and Financial Engineering offers numerous opportunities involving fairly deep mathematical concepts.
- Operations Researchers help organizations, businesses, and government find efficient solutions to organizational and strategic planning questions, including scheduling and distribution problems, resource allocation, facilities design, and forecasting.
- Mathematicians are frequently employed in Information Technology positions. In particular, mathematical knowledge is essential for work in information security and cryptography.
- Statisticians are employed by large organizations and work in research and development divisions from academia to industry to analyze data from surveys and experiments.
- Education offers a wide field of employment ranging from secondary school teachers to university professors.
- There are job opportunities in Engineering Mathematics in sectors from aerospace engineering and petroleum engineering to a wide range of other engineering disciplines.
- Last, but not least, mathematicians pursue academic careers at research institutes or universities.

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 worldwide network which provides support 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 Contacts

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

Dr. Keivan Mallahi-Karai

University Lecturer of Mathematics

Email: kmallahikarai@constructor.university

or visit our program website: https://constructor.university/programs/undergraduate-education/mathematics-modeling-data-analytics

For more information on Student Services please visit:

Student services | Constructor University

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 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.

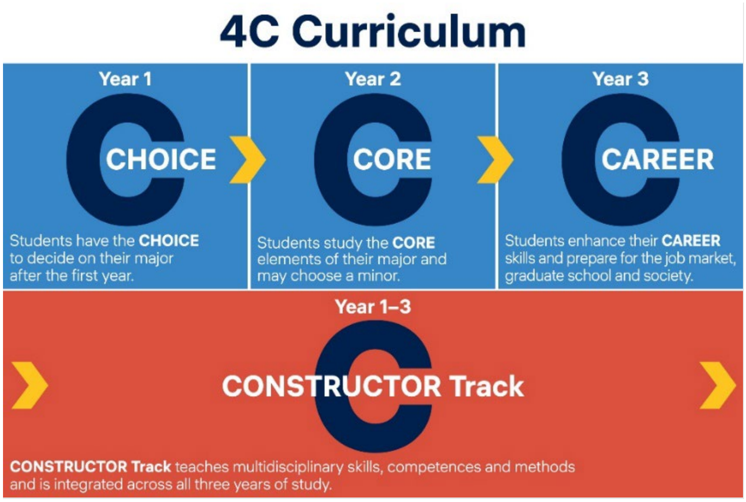

Figure 1: The Constructor University 4C-Model

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:

- 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)

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).

Analysis and Linear Algebra cover the foundations of the areas of calculus and linear algebra from a rigorous mathematical perspective. In addition, the modules Mathematical Modelling and either the CHOICE modules Core Algorithms and Data Structures or Algorithms and Data Structures provide the foundation for mathematical modeling and basic programming skills. These CHOICE modules are complemented by the Methods modules (Matrix Algebra and Advanced Calculus I + II) which equip students with complementary skills in calculus and linear algebra, see Section 2.2.4.1.

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 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:

- Physics and Data Science (PHDS)
  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)

- International Relations: Politics and History (IRPH)
  CHOICE Module: Introduction to International Relations Theory (m, 7.5 CP)

CHOICE Module: Introduction to Modern European History (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)

- Computer Sciene (CS)
  CHOICE Module: Programming in C and C++ (m, 7.5 CP)
  CHOICE Module: Algorithms and Data Structures (m, 7.5 CP)
  CHOICE Module: Introduction to Computer Science (m, 7.5 CP)
  CHOICE Module: Introduction to Robotics and Intelligent Systems (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 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 Mathematics, Modeling and Data Analytics as a major, 40 CP mandatory CORE modules need to be acquired:

- CORE Module: Algebra (m, 5 CP)
- CORE Module: Complex Analysis (m, 5 CP)
- CORE Module: Real Analysis (m, 5 CP)
- CORE Module: Number Theory (m, 5 CP)
- CORE Module: Discrete Mathematics (m, 5 CP)
- CORE Module: Computational Modeling (m, 5 CP)
- CORE Module: Machine Learning (m, 5 CP)
- CORE Module: Scientific Data Analysis (m, 5 CP)

Students complement their studies by taking 5 ECTS of the second/third year Specialization modules (please also see 2.2.3.2):

- MMDA Specialization: Topology and Differential Geometry (me, 5 CP)
- MMDA Specialization: Foundations of Mathematical Physics (me, 5 CP)
- MMDA Specialization: Stochastic Modeling and Financial Mathematics (me, 5 CP)
- MMDA Specialization: Dynamical Systems (me, 5 CP)
- MMDA Specialization: Stochastic Processes (me, 5 CP)

2.2.2.1 Minor Option

Mathematics, Modeling and Data Analytics do not have the option of taking a minor as the study program already combines different disciplines.

2.2.3 Year 3 – CAREER

During their third year, students prepare and make decisions for their career after graduation. To explore available choices, and to gain professional experience, students take a mandatory summer internship. The third year of studies allows Mathematics, Modeling and Data Analytics students to take specialization modules within their discipline, but also focuses on the responsibility of students beyond their discipline (see CONSTRUCTOR Track).

The 5th semester also opens a mobility window for ample study abroad options. Finally, the 6th semester is dedicated to fostering the research experience of students 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 their 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 free selections during their 5th and 6th semester.

To pursue Mathematics as a major, students take all in all 20 CP from mandatory elective Specialization modules

- MMDA Specialization: Stochastic Processes (me, 5 CP)
- MMDA Specialization: Foundations of Mathematical Physics (me, 5 CP)
- MMDA Specialization: Dynamical Systems (me, 5 CP)
- MMDA Specialization: Topology and Differential Geometry (me, 5 CP)
- MMDA Specialization: Stochastic Modeling and Financial Mathematics (me, 5 CP)

The following modules from Physics and Data Science and master's program in CSSE can substitute up to 5 CP of the above Specialization modules:

- PHDS CORE: Quantum Mechanics (me, 5 CP)
- PHDS CORE: Analytical Mechanics (me, 5 CP)

- PHDS Specialization: Particle Fields and Quanta (me, 5 CP)
- MSc CSSE Specialization: Quantum Informatics (5 CP)

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 a number of 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).

Mathematics, Modeling and Data Analytics 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 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 proficiency in 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 Faculty Supervisor, the Bachelor Thesis can also have an interdisciplinary nature. In the seminar, students present and discuss their theses in a course environment 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 Mathematics, Modelling and Data Analytics major, the following Methods modules (20 CP) need to be taken as mandatory modules:

- Methods: Matrix Algebra & Advanced Calculus I (m, 5 CP)
- Methods: Matrix Algebra & Advanced Calculus II (m, 5 CP)
- Methods: Probability and Random Processes (m, 5 CP)
- Methods: 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 enhance 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 Mathematics as a Minor

Mathematics is a good choice as a minor for a large range of other majors, as mathematical methods, analytic reasoning, and quantitative skills are useful or even essential in many other fields.

The Mathematics minor is very flexible, with the intention to substantially enhance mathematics skills, develop the ability to reason rigorously, and connect mathematical methods to diverse fields of application.

3.1 Qualification Aims

The key qualification aim is to develop rigorous mathematical thought as a universal transferable skill which can be used in almost all academic and professional environments. Along the way, a student must develop the necessary technical skills in the core areas Analysis and Linear Algebra. Apart from this, the choice of further subject modules is flexible, and students may opt for depth or breadth according to their own interest with the goal of building confidence in interacting with selected advanced mathematical concepts.

For students in Physics, Computer Science, and RIS, a minor in Mathematics, with an appropriate selection module, can directly develop competencies in the theoretical aspects of their chosen major. All other fields of study represented at Constructor University have, at least in the research arena, subfields that involve mathematical modeling, simulation, or theory which is greatly facilitated by a working knowledge of Mathematics corresponding to at least a minor, if not a major, in Mathematics.

3.1.1 Intended Learning Outcomes

With a minor in Mathematics, students will be able to

1. understand what constitutes a proof, distinguish heuristics from rigorous arguments, and find gaps in a chain of reasoning;
2. make rigorous mathematics arguments in Linear Algebra and Analysis, the two central subject areas in a structured mathematics curriculum;
3. understand the key concepts in at least two areas of mathematics, pure or applied, at a more advanced level;
4. solve basic problems by applying the standard methods in these fields,
5. recognize mathematical structures and formalize descriptions of concepts presented in common language;
6. be confident in using mathematical terminology and communicate with mathematicians and non-mathematicians on subjects of mutual interest.

3.2 Module Requirements

A minor in Mathematics requires 30 CP. The option to obtain a minor in Mathematics is marked in the Study and Examination Plan in Chapter 6.

It includes the following 15 CP of CHOICE Modules:

- CHOICE Module: Analysis (m, 7.5 CP)
- CHOICE Module: Linear Algebra (m, 7.5 CP)

The remaining 15 CP include the following second-year Mathematics CORE modules:

- CORE Module: Discrete Mathematics (m, 5 CP)
- CORE Module: Number Theory (m, 5 CP)
- CORE Module: Computational Modeling (m, 5 CP)

It is recommended that students who pursue a minor in Mathematics take the following METHODS Modules in their first year:

- Methods Module: Matrix Algebra and Advanced Calculus I (me, 5 CP)
- Methods Module: Matrix Algebra and Advanced Calculus II (me, 5 CP)

3.3 Degree

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

4 Mathematics, Modeling and Data Analytics Undergraduate Program Regulations

4.1 Scope of these Regulations

The regulations in this handbook are valid for all students who entered the Mathematics, Modeling and Data Analytics 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 https://constructor.university/student-life/student-services/university-policies/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). Constructor University reserves therefore the right to modify the regulations of the program handbook.

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 Mathematics, Modeling and Data Analytics.

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 Mathematics, Modeling and Data Analytics

Figure 1 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.

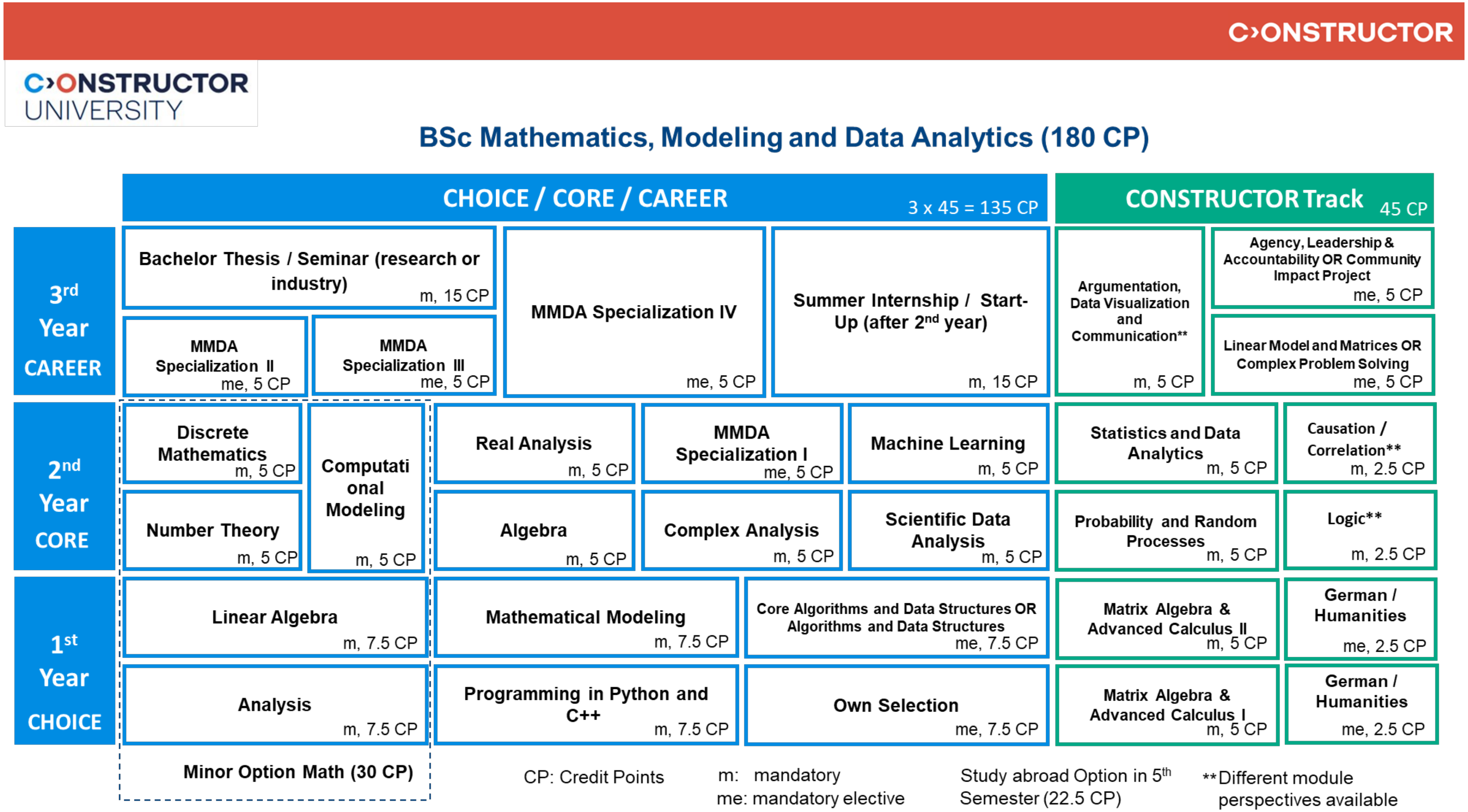

Figure 2: Schematic Study Plan for MMDA

Mathematics, Modeling and Data Analytics 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, this is a requirement for the Mathematics, Modeling and Data Analytics program.							
	Unit: Foundations of Mathematics (Minor)						**7.5**
CH-150	**Module: Analysis (Minor)**				**m**	**1**	**7.5**
CH-150-A	Analysis	Lecture	Written Examination	Examination period			
CH-151	**Module: Linear Algebra (Minor)**				**m**	**2**	**7.5**
CH-151-A	Linear Algebra	Lecture	Written Examination	Examination period			
	Unit: Programming and Mathematical Modeling						**15**
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	Tutorial	Laboratory report	During the semester			2.5
Take one of the two mandatory elective CHOICE modules listed below, this is a requirement for the Mathematics, Modelling and Data Analytics 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			2.5
SDT-102-B	Core Algorithms and Data Structures Lab	Lab	Practical Assessment	During the semester			5
CH-231	**Module: Algorithms and Data Structures**				**me**	**2**	**7.5**
CH-231-A	Algorithms and Data Structures	Lecture	Written Examination	Examination period			
	Unit: CHOICE (own selection)				**me**	**1**	**7.5**
Students take one further CHOICE module (7.5 CP) from those offered for all other study programs.[2]							
Year 2 - CORE							**45**
Take all modules listed below or replace mandatory elective ("me") modules (15 CP) with suitable CORE modules from other study programs.							
	Unit: Default Minor Track						**15**
CO-500	**Module: Number Theory (Minor)[2]**				**m**	**3**	**5**
CO-500-A	Number Theory	Lecture	Written Examination	Examination period			
CO-501	**Module: Discrete Mathematics (Minor)[2]**				**m**	**4**	**5**
CO-501-A	Discrete Mathematics	Lecture	Written Examination	Examination period			
CO-482	**Module: Computational Modeling (Minor)[2]**				**m**	**3/4**	**5**
CO-482-A	Computational Modeling I	Lecture	Project Assessment	During the semester		3	2.5
CO-482-B	Computational Modeling II	Lecture				4	2.5
	Unit: Core Mathematics						**15**
CO-505	**Module: Algebra**				**m**	**3**	**5**
CO-505-A	Algebra	Lecture	Written Examination	Examination period			
CO-506	**Module: Complex Analysis**				**m**	**3**	**5**
CO-506-A	Complex Analysis	Lecture	Written Examination	Examination period			
CO-507	**Module: Real Analysis**				**m**	**4**	**5**
CO-507-A	Real Analysis	Lecture	Written Examination	Examination period			
	Unit: Core Data Analytic						**15**
CO-450	**Module: Scientific Data Analysis**				**m**	**3**	**5**
CO-450-A	Scientific Data Analysis	Lecture	Portfolio Assessment	During semester			
CO-541	**Module: Machine Learning**				**m**	**4**	**5**
CO-541-A	Machine Learning	Lecture	Written Examination	Examination period			
CA-S-MMDA	**Module: MMDA Specialization I**				**me**	**4**	**5**
	Take 5 CP of MMDA Specialization Modules						
Year 3 - CAREER							**45**
CA-INT-900	**Module: Internship / Startup and Career Skills**				**m**	**4/5**	**15**
CA-INT-900-0	Internship / Startup and Career Skills		Project Report	During the 5th semester			15
CA-MMDA-800	**Module: Seminar / Thesis Mathematics, Modelling and Data Analytics**				**m**	**6**	**15**
CA-MMDA-800-T	Thesis Mathematics, Modelling and Data Analytics	Thesis	Thesis	15th of May			12
CA-MMDA-800-S	Thesis Seminar Mathematics, Modelling and Data Analytics	Seminar	Presentation	During the semester			3
	Unit: Specialization Mathematics, Modelling and Data Analytics				**me**	**5/6**	**15**
Take a total of 15 CP of specialization modules.							
CA-S-MMDA-805	**Module: Stochastic Processes**				**me**	**4/6**	**5**
CA-MMDA-805	Stochastic Processes	Lecture	Written Examination	Examination period			
CA-S-MMDA-804	**Module: Dynamical Systems**				**me**	**5/6**	**5**
CA-MMDA-804	Dynamical Systems	Lecture	Written Examination	Examination period			
CA-S-MMDA-802	**Module: Foundations of Mathematical Physics**				**me**	**3/5**	**5**
CA-MMDA-802	Foundations of Mathematical Physics	Lecture	Written Examination	Examination period			
CA-S-MMDA-801	**Module: Topology and Differential Geometry**				**me**	**5/6**	**5**
CA-MMDA-801	Topology and Differential Geometry	Lecture	Written Examination	Examination period			
CA-S-MMDA-803	**Module: Stochastic Modeling and Financial Mathematics**				**me**	**5/6**	**5**
CA-MMDA-803	Stochastic Modeling and Financial Mathematics	Lecture	Portfolio Assessment	During the semester			
The following modules can substitute up to 5 CP of the above							
CO-481	**Module: Quantum Mechanics**				**me**	**4/6**	**5**
CO-481-A	Quantum Mechanics	Lecture	Written Examination	Examination period			
CO-480	**Module: Analytical Mechanics**				**me**	**5**	**5**
CO-480-A	Analytical Mechanics	Lecture	Written Examination	Examination period			
CA-S-PHDS-802	**Module: Particle Fields and Quanta**				**me**	**4/6**	**5**
CA-PHDS-802-A	Elementary Particles and Fields	Lecture	Project Assessment	During the sememster			2.5
CA-PHDS-802-B	Advanced Quantum Physics	Lecture					2.5
MCSSE-BA-01	**Module: Quantum Informatics**				**me**		**5**
MCSSE-BA-01-A	Quantum Informatics	Lecture	Written Examination	Examination period			2.5
MCSSE-BA-01-B	Quantum Informatics Lab	Lab	Portfolio Assessment	During the sememster			2.5
Total CP							**180**

	Constructor Track Modules (General Education)	Type	Assessment	Period	Status[1]	Sem.	CP
Year 1							**15**
	Unit: 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)				**m**		**5**
German is default language and open to Non-German speakers (on campus and online).[4]							
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 to 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	**Introduction to Visual Culture**				**me**	**2**	**2.5**
CTHU-003	Introduction to Visual Culture	Lecture (online)	Written Examination	Examination period			
Year 2							
	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**		**2.5**
CTNS-02	Logic (perspective II)	Lecture (online)	Written Examination	Examination period			
Choose one of the two modules							
CTNS-NSK-03	**Module: Causation and Correlation (perspective I)**				**me**	**4**	**2.5**
CTNS-03	Causation and Correlation (perspective I)	Lecture (online)	Written Examination	Examination period			
CTNS-NSK-04	**Module: Causation and Correlation (perspective II)**				**me**	**4**	**2.5**
CTNS-04	Causation and Correlation (perspective II)	Lecture (online)	Written Examination	Examination period			
Year 3							**15**
	Unit: New Skills						**10**
Choose one of the two modules							
CTNS-NSK-05	**Module: Linear Model / Matrices**				**me**	**5**	**5**
CTNS-05	Linear Model/ 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, Leadership, and Accountability**				**me**	**6**	**5**
CTNS-09	Agency, Leadership, and Accountability	Lecture (online)	Written Examination	Examination period			
CTNS-CIP-10	**Module: Community Impact Project**				**me**	**5/6**	**5**
CTNS-10	Community Impact Project	Project	Project Assessment	Examination period			

[1] Status (m = mandatory, me = mandatory elective)

[2] For a full listing of all CHOICE / CORE / CAREER / Constructor Track modules please consult the CampusNet online catalogue and /or the study program handbooks.

[3] German native speakers will have alternatives to the language courses (in the field of Humanities).

[4] Humanities I and II are optional to all students, except for German native speakers.

Figure 3: Study and Examination Plan

7 Mathematics, Modeling and Data Analytics Modules

7.1 Analysis

<table>
<tr><td colspan="3">Module Name
Analysis</td><td>Module Code
CH-150</td><td>Level (type)
Year 1 (CHOICE)</td><td>CP
7.5</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>CH-150-A</td><td colspan="3">Analysis</td><td>Lecture</td><td>7.5</td></tr>
<tr><td>Module Coordinator

Prof. Dr. Sören Petrat</td><td colspan="3">Program Affiliation

• Mathematics, Modeling and Data Analytics (MMDA)</td><td colspan="2">Mandatory Status

Mandatory for SDT, MMDA, and Minor in Mathematics</td></tr>
<tr><td colspan="3" rowspan="2">Entry Requirements

Pre-requisites: ☒ None
Co-requisites: ☒ None
Knowledge, Abilities, or Skills:
• Good command of high-school mathematics, in particular pre-calculus topics
• Good command of high-school calculus helps, but is not a prerequisite</td><td>Frequency

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

• Lectures (35 hours)
• Tutorials (17.5 hours)
• Private study (135 hours)</td></tr>
<tr><td>Duration

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

187.5 hours</td></tr>
</table>

Recommendations for Preparation

- It is recommended to co-enroll in the Methods module “Matrix Algebra & Advanced Calculus I”
- Revise your high school mathematics
- Read general interest expositions about mathematics and mathematicians
- Work on mathematics problems over the summer

For a detailed set of preparation instruction, references, and links, see http://math.Constructor-university.de/undergraduate/prepare/index.php

Content and Educational Aims

This module introduces fundamental concepts and techniques in a concise and rigorous way. The class conveys the pleasure of doing mathematics, and motivates mathematics concepts from problems and concrete examples, but also shows the power of abstraction and of formal reasoning.

The following topics will be covered:

- Proof by induction, and elementary combinatorics
- Groups, equivalence relations, and quotients
- Natural numbers, integers, rationals, and real numbers
- Sequences and series, and convergence
- Functions of a single real variable, continuity, and the intermediate value theorem,
- Metric spaces, and the continuous functions as a metric space
- Differentiation, mean value theorem, and the inverse mapping theorem in one variable
- Riemann integral

- Fundamental theorem of Calculus, and the integration by parts with applications
- Integral mean value theorem
- Change of variables
- Taylor series with integral and Lagrange remainders
- Elementary point-set topology (neighborhoods, open and closed sets, compactness, and Heine-Borel)

Intended Learning Outcomes

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

1. cleanly formulate mathematical concepts and results discussed in class;
2. outline proofs which have been given in the lectures;
3. independently prove results which are direct consequences of those proved in the lectures;
4. understand and use fundamental mathematical terminology to communicate mathematics at a university level.

Indicative Literature

W. Rudin (1976). Principles of Mathematical Analysis, third edition. New York: McGraw-Hill.

T. Tao (2016). Analysis, third edition. New Delhi: Hindustan Book Agency.

Usability and Relationship to other Modules

- This module is part of the core education in Mathematics, Modeling and Data Analytics.
- It is also valuable for students in Physics, Computer Science, RIS, and ECE, either as part of a minor in Mathematics, or as an elective module.
- The curriculum is integrated with the curriculum of the module "Matrix Algebra and Advanced Calculus" in the following way: "Matrix Algebra and Advanced Calculus" emphasizes the operational aspects, computational skills, and intuitive understanding, while Analysis builds rigorous foundations of the field, emphasizing proof, abstraction, and mathematical rigor.

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%.

7.2 Linear Algebra

<table>
<tr><td colspan="3">Module Name
Linear Algebra</td><td>Module Code
CH-151</td><td>Level (type)
Year 1 (CHOICE)</td><td>CP
7.5</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>CH-151-A</td><td colspan="3">Linear Algebra</td><td>Lecture</td><td>7.5</td></tr>
<tr><td>Module Coordinator

Dr. Ivan Ovsyannikov</td><td colspan="3">Program Affiliation

• Mathematics, Modeling and Data Analytics (MMDA)</td><td colspan="2">Mandatory Status

Mandatory for MMDA, and minor in Mathematics
Mandatory elective for SDT</td></tr>
<tr><td colspan="3" rowspan="2">Entry Requirements

Pre-requisites
☒ None

Co-requisites
☒None

Knowledge, Abilities, or Skills
• Basic matrix algebra at the level achieved in “Matrix Algebra and Advanced CalculusI”</td><td>Frequency

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

• Lectures (35 hours)
• Tutorials (17.5 hours)
• Private study (135 hours)</td></tr>
<tr><td>Duration

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

187.5 hours</td></tr>
</table>

Recommendations for Preparation

- Revise your matrix algebra.
- Unless prepared otherwise, take the Methods module “Matrix Algebra and Advanced Calculus I” in the first semester.

Content and Educational Aims

This module continues the introduction to Linear Algebra from the methods module “Matrix Algebra and Advanced Calculus I"”. The fundamental concepts and techniques of Linear Algebra are introduced in a rigorous and more abstract way. The first half of this module covers vector spaces and linear maps, while the second half covers inner products and geometry.

The following topics will be covered:

- Vector spaces
- Linear Operators
- Dual spaces
- Isomorphisms
- Connection to matrices
- Sums and direct sums
- Fundamental spaces of a linear operator
- Diagonalization of linear operators (on finite dimensional spaces)
- Cayley-Hamilton theorem
- Jordan decomposition
- Jordan normal form and its applications to linear differential equations
- Decomplexification and complexification
- Bilinear Forms and their classification
- Quadratic forms and orthogonalization
- Euclidean and unitary spaces
- Orthogonal and unitary operators
- Self-adjoint operators

Intended Learning Outcomes

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

1. describe the concept of a vector space and linear operator in an abstract way
2. explain the connection of abstract linear algebra in the context of matrix algebra
3. discuss the proofs of the major theorems from class
4. illustrate the use of bilinear forms and their role in geometry
5. distinguish bilinear forms in the context of Euclidean, unitary and symplectic spaces

Indicative Literature

P.K. Kostrikin, Yu. Manin (1997) Linear Algebra and Geometry. London: Gordon and Breach.
S. Axler (2005) Linear Algebra Done Right, third edition. Berlin: Springer.
G. Strang (2016). Introduction to Linear Algebra. Wellesley: Wellesley-Cambridge Press, fifth edition.
S. Lang (1986). Introduction to Linear Algebra, second edition. Berlin: Springer.

Usability and Relationship to other Modules

- This module is part of the core education in Mathematics
- This module is valuable for students in Computer Science, RIS, and ECE, either as part of a minor in Mathematics, or as an elective module
- The curriculum is integrated with the curriculum of the module "Matrix Algebra and Advanced Calculus I and II" in the following way: "Matrix Algebra and Advanced Calculus I and II" emphasizes the operational aspects, computational skills, and intuitive understanding, while Linear Algebra builds rigorous foundations of the field, emphasizing proof, abstraction, and mathematical rigor.

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%.

7.3 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	**Program Affiliation**	**Mandatory Status**
Prof. Dr. Aleksander Omelchenko	• Software, Data and Technology (SDT)	Mandatory for SDT, MMDA, PHDS Minor in SDT, PHDS, and MMDA Mandatory elective for ECE

Entry Requirements			**Frequency**	**Forms of Learning and Teaching**
Pre-requisites ☒ none	Co-requisites ☒ none	Knowledge, Abilities, or Skills ☒ none	Annually (Fall)	• 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%

7.4 Mathematical Modeling

Module Name		**Module Code**	**Level (type)**	**CP**
Mathematical Modeling		CH-152	Year 1 (CHOICE)	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 andDr. 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, Christof, Harald Garcke, and Peter Knabner. Mathematical modeling. Berlin: Springer International Publishing, 2017.

Usability and Relationship to other Modules

- This module is part of the core education in 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 Examinations

Module Component 1: Mathematical Modeling
Assessment Type: Written examination Duration/length: 120 min
Weight: 67% (weighted according CP)
Scope: All intended learning outcomes of this module

Module Component 2: Mathematical Modeling Lab
Assessment Type: Practical assessment (Homework assignments)
Weight: 33% (weighted according CP)
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%

7.5 Core Algorithms and Data Structures

<table>
<tr><td colspan="3">Module Name

Core Algorithms and Data Structures</td><td>Module Code

SDT-102</td><td>Level (type)

Year 1 (CHOICE)</td><td>CP

7.5</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>SDT-102-A</td><td colspan="3">Core Algorithms and Data Structures</td><td>Lecture</td><td>5</td></tr>
<tr><td>SDT-102-B</td><td colspan="3">Core Algorithms and Data Structures - Lab</td><td>Lab</td><td>2.5</td></tr>
<tr><td>Module Coordinator

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

• Software, Data and Technology (SDT)</td><td colspan="2">Mandatory Status

Mandatory for SDT and minor in SDT

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

Pre-requisites: ☒ Programming in Python and C++ OR Programming in C/C++
Co-requisites: ☒ none
Knowledge, Abilities, or Skills: •</td><td>Frequency

Annually

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

• Lecture (35 hours)
• Tutorial (17.5 hours)
• Independent study (115 hours)
• Exam preparation (20 hours)</td></tr>
<tr><td>Duration

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

187.5 hours</td></tr>
</table>

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: Written examination | Duration: 120 min

Weight: 67%

Scope: All theoretical intended learning outcomes of the module

Component 2: Lab

Assessment: 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

<table>
<tr><td colspan="3">Module Name
Algorithms and Data Structures</td><td>Module Code
CH-231</td><td>Level (type)
Year 1 (CHOICE)</td><td>CP
7.5</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>CH-231-A</td><td colspan="3">Algorithms and Data Structures</td><td>Lecture</td><td>7.5</td></tr>
<tr><td>Module Coordinator

Dr. Kinga Lipskoch</td><td colspan="3">Program Affiliation

• Computer Science (CS)</td><td colspan="2">Mandatory Status

Mandatory for CS, RIS and minor in CS
Mandatory elective for PHDS and MDDA</td></tr>
<tr><td colspan="3" rowspan="2">Entry Requirements

Pre-requisites: ☒ Programming in C and C++ or Programming in Python and C++
Co-requisites: ☒ None
Knowledge, Abilities, or Skills:</td><td>Frequency

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

• Class attendance (52.5 hours)
• Independent study (115 hours)
• Exam preparation (20 hours)</td></tr>
<tr><td>Duration

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

187.5 hours</td></tr>
</table>

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 Number Theory

Module Name Number Theory			Module Code CO-500	Level (type) Year 2 (CORE)	CP 5
Module Components					
Number	Name			Type	CP
CO-500-A	Number Theory			Lecture	5
Module Coordinator Dr. Keivan Mallahi Karai	**Program Affiliation** • Mathematics, Modeling and Data Analytics (MMDA)			**Mandatory Status** Mandatory for MMDA	
Entry Requirements Pre-requisites ☒ None	Co-requisites ☒ None	Knowledge, Abilities, or Skills • Basic university mathematics: can be acquired via the Methods Modules Matrix Algebra and Advanced Calculus I + II	**Frequency** Annually (Fall) **Duration** 1 semester	**Forms of Learning and Teaching** • Lectures (35 hours) • Private study (90 hours) **Workload** 125 hours	
Recommendations for Preparation It is recommended to have taken the Methods module: Matrix Algebra and Advanced Calculus I, II. Some basic familiarity with linear algebra is useful, but not technically required.					
Content and Educational Aims This module is an elementary introduction to number theory, whose aim is to familiarize the audience with the classical ideas and methods of the field, as well as some of its more recent applications especially in cryptography and related technologies. Topics covered in this module include prime numbers and their distribution, the fundamental theorem of arithmetic, modular arithmetic, primitive roots, finite fields, applications to modern cryptography (e.g., RSA cryptographic platform), discrete logarithm problem, applications to error correcting codes, and quadratic reciprocity. The second part of the module is more topical and deals with more advanced topics such as Riemann Zeta function, primes in arithmetic progressions, continued fractions and diophantine approximations, Pell's equation, Minkowski's Geometry of numbers, the Gauss circle problem, and related lattice point counting problems.					
Intended Learning Outcomes By the end of the module, students will be able to 1. demonstrate their mastery of basic tools of number theory; 2. develop the ability to use number theoretic concepts and structures for applications in cryptographic platforms; 3. analyze the definitions of basic number theoretical concepts such as primes numbers, congruences, and finite fields;					

4. formulate and design methods and algorithms for solving applied problems using tools from number theory.

Indicative Literature

A. Weil (1976). Number Theory for Beginners. Berlin: Springer.
T.M. Apostol (1976). Introduction to Analytic Number Theory. Berlin: Springer.
N. Koblitz (1994). A course in Number Theory and Cryptography, second edition. Berlin: Springer.

Usability and Relationship to other Modules

- It is recommended as a module toward a minor in Mathematics to be taken in Semester 3.
- It is a useful elective for students majoring in Computer Science, RIS, and ECE.

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 examinations must be passed with at least 45%.

7.8 Discrete Mathematics

<table>
<tr><td colspan="3">Module Name

Discrete Mathematics</td><td>Module Code

CO-501</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-501-A</td><td colspan="3">Discrete Mathematics</td><td>Lecture</td><td>5</td></tr>
<tr><td>Module Coordinator

Dr. Keivan Mallahi-Karai</td><td colspan="3">Program Affiliation

• Mathematics, Modeling and Data Analytics (MMDA)</td><td colspan="2">Mandatory Status

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

Pre-requisites: ☒ None

Co-requisites: ☒ None

Knowledge, Abilities, or Skills:
• Basic university mathematics: can be acquired via the Methods Modules “Calculus and Elements of Linear Algebra I + II” or Matrix Algebra and Advanced Calculus.</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 familiarity with linear algebra is useful, but not technically required.
• It is recommended to have taken the Methods module: Calculus and Elements of Linear Algebra I + II</td></tr>
<tr><td colspan="6">Content and Educational Aims

This module is an introductory lecture in discrete mathematics. The lecture consists of two main components, enumerative combinatorics and graph theory. The lecture emphasizes connections of discrete mathematics with other areas of mathematics such as linear algebra and basic probability, and outlines applications to areas of computer science, cryptography, etc. where employment of ideas from discrete mathematics has proven to be fruitful. The first part of the lecture—enumerative combinatorics—deals with several classical enumeration problems (Binomial coefficients, Stirling numbers), counting under group actions and generating function. The second half of the lecture—graph theory—includes a discussion of basic notions such as chromatic number, planarity, matchings in graphs, Ramsey theory, and expanders, and their applications.</td></tr>
</table>

Intended Learning Outcomes

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

1. demonstrate their mastery of basic tools in discrete mathematics.
2. develop the ability to use discrete mathematics concepts (such as graphs) to model problems in computer science.
3. analyze the definition of basic combinatorial objects such as graphs, permutations, partitions, etc.
4. formulate and design methods and algorithms for solving applied problems based on concepts from discrete mathematics.

Indicative Literature

J.H. van Lint and R.M. Wilson (2001). A Course in Combinatorics, second edition. Cambridge: Cambridge University Press.

B. Bollobas (1998). Modern Graph Theory, Berlin: Springer.

Usability and Relationship to other Modules

- This module is recommended for students pursuing a minor in Mathematics
- This module is a good option as an elective module for students in RIS.

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 examinations must be passed with at least 45%.

7.9 Computational Modeling

<table>
<tr><td colspan="3">Module Name
Computational Modeling</td><td>Module Code
CO-482</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-482-A</td><td colspan="3">Computational Modeling I</td><td>Lecture</td><td>2.5</td></tr>
<tr><td>CO-482-B</td><td colspan="3">Computational Modeling II</td><td>Lecture</td><td>2.5</td></tr>
<tr><td>Module Coordinator
Prof. Dr. Ulrich Kleinekathöfer</td><td colspan="3">Program Affiliation
• Physics and Data Science (PHDS)</td><td colspan="2">Mandatory Status
Mandatory for PHDS and MMDA</td></tr>
<tr><td colspan="3">Entry Requirements</td><td>Frequency
Annually
(Fall and Spring)</td><td colspan="2">Forms of Learning and Teaching
• Lecture (35 hours)
• Private study (35 hours)
• Exercises and project (55 hours)</td></tr>
<tr><td>Pre-requisites
☒ Mathematical Modeling</td><td>Co-requisites
☒ None</td><td>Knowledge, Abilities, or Skills
• Basics of scientific programming preferably in Python</td><td>Duration
2 semesters</td><td colspan="2">Workload
125 hours</td></tr>
</table>

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 Assessment 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 Algebra

<table>
<tr><td colspan="3">Module Name
Algebra</td><td>Module Code
CO-505</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-505-A</td><td colspan="3">Algebra</td><td>Lecture</td><td>5</td></tr>
<tr><td>Module Coordinator
Dr. Keivan Mallahi Karai</td><td colspan="3">Program Affiliation
• Mathematics, Modeling and Data Analytics (MMDA)</td><td colspan="2">Mandatory Status
Mandatory for MMDA</td></tr>
<tr><td colspan="3" rowspan="2">Entry Requirements
Pre-requisites: ☒ Linear Algebra
Co-requisites: ☒None
Knowledge, Abilities, or Skills: • None beyond formal pre-requisites</td><td>Frequency
Annually (Fall)</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
Review material from Linear Algebra</td></tr>
<tr><td colspan="6">Content and Educational Aims
This module is an introduction to abstract algebra, which covers a range of topics from basic notions and methods in group theory to elements of ring theory and basic field theory. The module presupposes a knowledge of linear algebra. The module covers basic constructions in group theory in more detail, such as quotient groups, direct and semi-direct products, special classes of groups (e.g. matrix groups, permutation groups), specific types of groups (nilpotent, solvable, and simple), basic examples of rings (e.g., polynomial rings, integral domains), and divisibility theory in commutative rings (principal ideal domains and unique factorization domains). The module also includes a basic introduction to the theory of fields, including field extensions and algebraic and transcendental extensions and the existence of splitting fields for polynomials over fields.</td></tr>
<tr><td colspan="6">Intended Learning Outcomes
By the end of the module, students will be able to
1. demonstrate their mastery of basic methods and concepts from Algebra to independently solve problems in that field;
2. assess the crucial importance of group theory and its applications to different areas of math;
3. explain the definitions of groups, rings, ideals, fields, and modules;
4. compare different examples of groups, rings, ideals, fields and modules from MMDA and PHDS.</td></tr>
</table>

Indicative Literature

J.B. Fraleigh (2002). A First Course in Abstract Algebra, seventh edition. New York: Pearson.

E.B. Vinberg (2003). A Course in Algebra, Rhode Island: AMS.

Usability and Relationship to other Modules

- It may be taken toward the graduation requirements for a minor in Mathematics; in this case, it is particularly useful for students with an interest in pure mathematics.

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 must be passed with at least 45%.

7.11 Complex Analysis

Module Name	Module Code	Level (type)	CP
Complex Analysis	CO-506	Year 2 (CORE)	5

Module Components

Number	Name	Type	CP
CO-506-A	Complex Analysis	Lecture	5

Module Coordinator	Program Affiliation	Mandatory Status
Prof. Dr. Igors Gorbovickis	• Mathematics, Modeling and Data Analytics (MMDA)	Mandatory for MMDA

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)
☒ Analysis	☒ None	• None beyond formal pre-requisites	**Duration** 1 semester	**Workload** 125 hours

Recommendations for Preparation

Review material from pre-requisite modules

Content and Educational Aims

The theory of complex-differentiable functions in one variable is a rich theory with powerful results: unlike differentiability for real functions, for example, if a function is complex differentiable, then this implies that it is differentiable infinitely often and that it is represented by its Taylor series in a neighborhood of every point in its domain of definition. This results in a very nice and elegant theory that is used in many areas of mathematics.

Topics covered in this module include holomorphic functions, Cauchy integral theorem and formula, Liouville's theorem, fundamental theorem of algebra, isolated singularities and Laurent series, analytic continuation and monodromy theorem, residue theorem, normal families, and the Riemann mapping theorem.

Intended Learning Outcomes

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

1. apply the methods from the field of Complex Analysis to solve mathematical problems in that field independently;
2. give precise proofs of the basic results of the subject;
3. calculate complex derivatives, integrals and series expansions;
4. compute integrals using the residue theorem;
5. apply Cauchy’s theorem, Liouville's theorem, monodromy theory, and the Riemann mapping theorem
6. be in a position of initiating a study of the Riemann surfaces or the higher-dimensional theory.

Indicative Literature

R. Narasimhan (1985). Complex Analysis One Variable. Basel: Birkhäuser.
L. Ahlfors (1980). Complex Analysis, 3rd Edition. New York: McGraw Hill.

Usability and Relationship to other Modules

- This module is a CORE module in Mathematics, Modeling and Data Analytics and can also be used by students in PHDS or students minoring in Mathematics.

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 must be passed with at least 45%.

7.12 Real Analysis

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

Real Analysis</td><td>Module Code

CO-507</td><td>Level (type)

Year 2 (CORE)</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>CO-507-A</td><td colspan="2">Real Analysis</td><td>Lecture</td><td>5</td></tr>
<tr><td>Module Coordinator

Prof. Dr. Igors Gorbovickis</td><td colspan="2">Program Affiliation

• Mathematics, Modeling and Data Analytics (MMDA)</td><td colspan="2">Mandatory Status

Mandatory for MMDA</td></tr>
<tr><td colspan="2" rowspan="2">Entry Requirements

Pre-requisites
☒ Analysis

Co-requisites
☒ None

Knowledge, Abilities, or Skills
• None beyond formal pre-requisites</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="5">Recommendations for Preparation

Review material from Analysis and Matrix Algebra and Advanced Calculus I, II.</td></tr>
<tr><td colspan="5">Content and Educational Aims

This module continues Analysis and Matrix Algebra & Advanced Calculus I, II by introducing Lebesgue integration as well as elements of Functional Analysis and Fourier methods in the concrete setting of Lebesgue spaces. The Lebesgue integral (that can be viewed as a generalization of the Riemann integral) requires a more involved framework, but offers powerful natural limit theorems and is also the basis for the Lebesgue function spaces that provide a natural setting for many problems in nonlinear analysis, mathematical physics, and partial differential equations.

The development of the subject starts with an introduction to measure theory with a rigorous construction of the Lebesgue measure and the Lebesgue integral. Emphasis is placed on the limit theorems (Fatou’s lemma, monotone convergence, and dominated convergence) and their consequences. It concludes with the introduction of Lebesgue spaces and their basic properties, Hilbert spaces, orthonormal systems and Fourier coefficients, Fourier transform.</td></tr>
<tr><td colspan="5">Intended Learning Outcomes

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

1. illustrate the central importance of measures and the Lebesgue integral in mathematics;
2. compare the Riemann and Lebesgue integrals and their role in Analysis;
3. use the central limit theorems in a variety of contexts;
4. formulate and employ the central properties of Lebesgue spaces, Hilbert spaces and Fourier analysis;</td></tr>
</table>

Indicative Literature

H.L. Royden, P.M. Fitzpatrick (2017) Real Analysis, 4th edition. New York: Pearson.

Usability and Relationship to other Modules

- This module may be taken toward the graduation requirements for a minor in Mathematics; in this case, it is particularly useful for students with an interest in Analysis and/or Mathematical Physics

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 must be passed with at least 45%.

7.13 Scientific Data Analysis

<table>
<tr><td colspan="3">Module Name
Scientific Data Analysis</td><td>Module Code
CO-450</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-489 -A</td><td colspan="3">Scientific Data Analysis</td><td>Lecture</td><td>5</td></tr>
<tr><td>Module Coordinator

Prof. Dr. Veit Wagner</td><td colspan="3">Program Affiliation

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

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

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</td><td>Frequency

Annually (Fall)</td><td colspan="2">Forms of Learning and Teaching
• Lecture (35 hours)
• Homework exercises (55 hours)
• Private study (35 hours)</td></tr>
<tr><td>Duration

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

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

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 Analysisncluding 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%.

7.14 Machine Learning

<table>
<tr><td colspan="3">Module Name
Machine Learning</td><td>Module Code
CO-541</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-541-A</td><td colspan="3">Machine Learning</td><td>Lecture</td><td>5</td></tr>
<tr><td>Module Coordinator
Prof. Dr. Francesco Maurelli</td><td colspan="3">Program Affiliation
• Robotics and Intelligent Systems (RIS)</td><td colspan="2">Mandatory Status
Mandatory for MMDA, PHDS, RIS and minor in RIS
Mandatory elective for CS</td></tr>
<tr><td colspan="3">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” (CTMS-MAT-12)</td><td>Frequency
Annually
(Spring)</td><td colspan="2">Forms of Learning and Teaching
• Class attendance (35 hours)
• Private study (70 hours)
• Exam preparation (20 hours)</td></tr>
<tr><td colspan="4"></td><td>Duration
1 semester</td><td>Workload
125 hours</td></tr>
<tr><td colspan="6">Recommendations for Preparation
None</td></tr>
<tr><td colspan="6">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.</td></tr>
<tr><td colspan="6">Intended Learning Outcomes
By the end of this module, students should be able to</td></tr>
</table>

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 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%.

7.15 Topology and Differential Geometry

<table>
<tr><td colspan="3">Module Name
Topology and Differential Geometry</td><td>Module Code
CA-S-MMDA-801</td><td>Level (type)
Year 2/3 (Specialization)</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>CA-MMDA-801</td><td colspan="3">Topology and Differential Geometry</td><td>Lecture</td><td>5</td></tr>
<tr><td>Module Coordinator

Prof. Dr. Sören Petrat</td><td colspan="3">Program Affiliation

• Mathematics, Modelling, and Data Analytics (MMDA)</td><td colspan="2">Mandatory Status

Mandatory elective for MMDA and PHDS</td></tr>
<tr><td colspan="3">Entry Requirements</td><td>Frequency

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

• Lectures (35 hours)
• Private Study (90 hours)</td></tr>
<tr><td>Pre-requisites

☒ Analysis</td><td>Co-requisites

☒ none</td><td>Knowledge, Abilities, or Skills

• Good command of Analysis and Linear Algebra</td><td>Duration

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

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

• Recap basic Analysis and Linear Algebra knowledge</td></tr>
<tr><td colspan="6">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, 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.</td></tr>
<tr><td colspan="6">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</td></tr>
<tr><td colspan="6">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.</td></tr>
</table>

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

7.16 Foundations of Mathematical Physics

Module Name			Module Code	Level (type)	CP
Foundations of Mathematical Physics			CA-S-MMDA-802	Year 2/3 (Specialization)	5
Module Components					
Number	Name			Type	CP
CA-MMDA-802	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			**Frequency** Biennially (Fall)	**Forms of Learning and Teaching** • Lectures (35 hours) • Private study (90 hours)	
Pre-requisites	Co-requisites	Knowledge, Abilities, or Skills			
☒ Mathematical modeling	☒None	• Good command of linear algebra, analysis, and calculus	**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 into 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 — 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%.

7.17 Stochastic Modeling and Financial Mathematics

<table>
<tr><td colspan="3">Module Name
Stochastic Modeling and Financial Mathematics</td><td>Module Code
CA-S-MMDA-803</td><td>Level (type)
Year 2 and 3 (Specialization)</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>CA-MMDA-803</td><td colspan="3">Stochastic Modeling and Financial Mathematics</td><td>Lecture</td><td>5</td></tr>
<tr><td>Module Coordinator

Prof. Dr. Sören Petrat</td><td colspan="3">Program Affiliation

• Mathematics, Modeling, and Data Analytics (MMDA)</td><td colspan="2">Mandatory Status

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

Pre-requisites: ☒ Matrix Algebra and Advanced Calculus I & II
Co-requisites: ☒ none
Knowledge, Abilities, or Skills: Good command of Calculus, Linear Algebra, and basic probability basic Python programming</td><td>Frequency

Annually (Spring/Fall)</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
• 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).</td></tr>
<tr><td colspan="6">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.</td></tr>
<tr><td colspan="6">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.</td></tr>
</table>

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. • A. 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, Modeling 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%.

7.18 Dynamical Systems

Module Name	**Module Code**	**Level (type)**	**CP**
Dynamical Systems	CA-S-MMDA-804	Year 2 and 3 (Specialization)	5

Module Components

Number	Name	Type	CP
CA-MMDA-804	Dynamical Systems	Lecture	5

Module Coordinator	**Program Affiliation**	**Mandatory Status**
Prof. Dr. Igors Gorbovickis	• Mathematics, Modeling, and Data Analytics (MMDA)	Mandatory elective for MMDA

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)
☒ 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 material from Analysis and Applied Mathematics

Content and Educational Aims

This module is an introduction to dynamical systems. Dynamical systems naturally arise from iterations of maps or from flows of vector fields on manifolds. The theory of dynamical systems has its roots in classical problems in celestial mechanics such as the three-body problem or statistical physics. The aim of this module is to introduce the participants to the most basic dynamical systems and to study their properties.

The module covers topics from discrete as well as continuous dynamical systems, including

- a review of linear differential and difference equations in arbitrary dimensions
- circle maps
- toral automorphisms, horseshoes, and the solenoid
- recurrence, topological transitivity, and periodic orbits
- topological mixing as well as their measure theoretic counterparts such as ergodicity
- stability
- differential equations in the plane and the Poincarè-Bendixon theorem
- chaotic dynamics, e.g., in the Lorenz system
- asymptotic techniques
- structural stability
- bifurcation theory
- rational maps on the Riemann sphere

Intended Learning Outcomes

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

1. demonstrate their mastery of advanced methods and concepts from Dynamical Systems to independently solve mathematical problems in that field;

2. assess the central importance of the theory of dynamical systems in analyzing the long-term behavior of continuous processes;
3. compare the qualitative behaviors of various dynamical systems;
4. qualitatively and quantitatively distinguish different forms of dynamical systems.

Indicative Literature

M. Brin, G. Stuck (2015). Introduction to Dynamical Systems, Cambridge: Cambridge University Press

M.W. Hirsch, S. Smale, R.L. Devaney (2012). Differential Equations, Dynamical Systems and Introduction to Chaos. Cambridge: Academic Press.

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 this module

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

7.19 Stochastic Processes

<table>
<tr><td colspan="3">Module Name

Stochastic Processes</td><td>Module Code

CA-S-MMDA-805</td><td>Level (type)

Year 2/3
(Specialization)</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>CA-MMDA-805</td><td colspan="3">Stochastic Processes</td><td>Lecture</td><td>5</td></tr>
<tr><td>Module Coordinator

Dr. Keivan Mallahi Karai</td><td colspan="3">Program Affiliation

• Mathematics, Modeling and Data Analytics (MMDA)</td><td colspan="2">Mandatory Status

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

Pre-requisites: ☒ Matrix Algebra and Advanced Calculus II and Probability and Random Processes

Co-requisites: ☒None

Knowledge, Abilities, or Skills: • None beyond formal pre-requisites</td><td>Frequency

Biennially
(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

Review of Probability and Analysis</td></tr>
<tr><td colspan="6">Content and Educational Aims

This module serves as an introduction to the theory of stochastic processes. It starts with a review of Kolmogorov axioms for probability spaces and continues by providing a rigorous treatment of topics such as the independence of events and Borel-Cantelli Lemma, Kolmogorov’s zero-one law, random variables, expected value and variance, the weak and strong laws of large numbers, and the Central limit theorem. More advanced topics that will follow include finite and countable state Markov chains, Galton-Watson trees, and the Wiener process. Several relevant applications that will be discussed are percolation on graphs, the application of Markov chains to sampling problems, and probabilistic methods in graph theory. The module also includes examples from mathematical finance.</td></tr>
<tr><td colspan="6">Intended Learning Outcomes
By the end of the module, students will be able to

1. demonstrate their mastery of basic stochastic methods;
2. develop ability to use stochastic processes to model real-world problems, e.g. in finance;
3. analyze the definition of basic probabilistic objects, and their numerical features;
4. formulate and design methods and algorithms for solving applied problems based on ideas from stochastic processes.</td></tr>
</table>

Indicative Literature

R. Durrette (2019). Probability: Theory and Examples. Cambridge: Cambridge University Press.

A. Koralov and Ya. Sinai (2007). Theory of Probability and Random Processes, Berlin: Springer.

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 this module

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

7.20 Quantum Mechanics

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

- One of three default 2nd year CORE modules for a minor in Physics

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%.

7.21 Analytical Mechanics

<table>
<tr><td colspan="3">Module Name

Analytical Mechanics</td><td>Module Code

CO-480</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-480-A</td><td colspan="3">Analytical Mechanics</td><td>Lecture</td><td>5</td></tr>
<tr><td>Module Coordinator

Prof. Dr. Peter Schupp</td><td colspan="3">Program Affiliation

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

Mandatory for PHDS
Mandatory elelctive MMDA</td></tr>
<tr><td rowspan="2" colspan="3">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</td><td>Frequency

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

• Lecture (35 hours)
• Homework exercises (55 hours)
• Private study (35 hours)</td></tr>
<tr><td>Duration
1 semester</td><td colspan="2">Workload
125 hours</td></tr>
<tr><td colspan="6">Recommendations for Preparation

Review classical mechanics, calculus and linear algebra at the level of the first-year courses.</td></tr>
<tr><td colspan="6">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</td></tr>
<tr><td colspan="6">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.</td></tr>
<tr><td colspan="6">Indicative Literature

D. Morin (2008). Introduction to Classical Mechanics: With Problems and Solutions. Cambridge: Cambridge University Press;</td></tr>
</table>

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
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%

7.22 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 Prof. Dr. Peter Schupp	**Program Affiliation** • Physics and Data Science (PHDS)			**Mandatory Status** Mandatory elective for PHDS and MMDA	
Entry Requirements Pre-requisites ☒ Quantum Mechanics and Analytical Mechanics. Alternatively, for both Foundations of Mathematical Physics	Co-requisites	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, project/presentation (55 hours) • Private study (35 hours)	
			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 Assessment   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%.

7.23 Quantum Informatics

Module Name		**Module Code**	**Level (type)**	**CP**
Quantum Informatics		MCSSE-BA-01	Year 2	5
Module Components				
Number	Name		Type	CP
MCSSE-BA-01-A	Quantum Informatics		Lecture	2.5
MCSSE-BA-01-B	Quantum Informatics Lab		Lab	2.5
Module Coordinators Prof. Dr. Peter Schupp, Prof. Dr. Stefan Kettemann	**Program Affiliation** • MSc Computer Science & Software Engineering		**Mandatory Status** Mandatory elective for MSc CSSE Mandatory elective for 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%

7.24 Internship / Startup and Career Skills

Module Name	Module Code	Level (type)	CP
Internship / Startup and Career Skills	CA-INT-900	Year 3 (CAREER)	15

Module Components

Number	Name	Type	CP
CA-INT-900-0	Internship	Internship	15

Module Coordinator	Program Affiliation	Mandatory Status
Sinah Vogel & Dr. Tanja Woebs (CSC Organization); SPC / Faculty Startup Coordinator (Academic responsibility)	• CAREER module for undergraduate study programs	Mandatory for all undergraduate study programs except IEM

Entry Requirements

Pre-requisites	Co-requisites	Knowledge, Abilities, or Skills
☒ at least 15 CP from CORE modules in the major	☒ None	• Information provided on CSC pages (see below) • Major specific knowledge and skills

Frequency	Forms of Learning and Teaching
Annually (Spring/Fall)	• Internship/Start-up • Internship event • Seminars, info-sessions, workshops and career events • Self-study, readings, online tutorials

Duration	Workload
1 semester	375 Hours consisting of: • Internship (308 hours) • Workshops (33 hours) • Internship Event (2 hours) • Self-study (32 hours)

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

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 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: Project Report	Length: approx. 3.500 words
Scope: All intended learning outcomes	Weight: 100%

7.25 Bachelor Thesis and Seminar in MMDA

<table>
<tr><td colspan="3">Module Name
Bachelor Thesis MMDA</td><td>Module Code
CA-MMDA-800</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-MMDA-800-T</td><td colspan="3">Bachelor Thesis MMDA</td><td>Thesis</td><td>12</td></tr>
<tr><td>CA-MMDA-800-S</td><td colspan="3">Thesis Seminar MMDA</td><td>Seminar</td><td>3</td></tr>
<tr><td>Module Coordinator
Study Program Chair</td><td colspan="3">Program Affiliation
• All undergraduate programs</td><td colspan="2">Mandatory Status
Mandatory for all undergraduate programs</td></tr>
<tr><td colspan="3">Entry Requirements</td><td>Frequency
Annually (Spring)</td><td colspan="2">Forms of Learning and Teaching
• Self-study/lab work (350 hours)
• Seminars (25 hours)</td></tr>
<tr><td>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.</td><td>Co-requisites

☒ None</td><td>Knowledge, Abilities, or Skills

• Comprehensive knowledge of the subject and deeper insight into the chosen topic;
• ability to plan and undertake work independently;
• skills to identify and critically review literature.</td><td>Duration
14-week lecture period</td><td colspan="2">Workload
375 hours</td></tr>
<tr><td colspan="6">Recommendations for Preparation
• 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 that you possess all required technical research skills or are able to acquire them on time.
• Review the University's Code of Academic Integrity and Guidelines to Ensure Good Academic Practice.</td></tr>
<tr><td colspan="6">Content and Educational Aims
This module is a mandatory graduation requirement for all undergraduate students to demonstrate their ability to deal with a problem from their respective major subject independently by means of academic/scientific methods within a set period. Although supervised, the module requires students to be able to work independently and regularly and set their own goals in exchange for the opportunity to explore a topic that excites and interests them personally and which a faculty member is interested to supervise. Within this module, students apply their acquired knowledge about the major discipline, skills, and methods to conduct research, ranging from the identification of suitable (short-term) research projects, preparatory literature searches, the realization of discipline-specific research, and the documentation, discussion, interpretation and communication of the results.

This module consists of two components, an independent thesis and an accompanying seminar. The thesis component must be supervised by a Constructor University faculty member and requires short-term research work, the results of which must be documented in a comprehensive written thesis including an introduction, a justification of the methods, results, a discussion of the results, and conclusions. The seminar provides students with the opportunity to present, discuss and justify their and other students' approaches, methods and results at various stages of their research to practice</td></tr>
</table>

these skills to improve their academic writing, receive and reflect on formative feedback, thereby growing personally and professionally.

Intended Learning Outcomes

On completion of this module, students should be able to

1. independently plan and organize advanced learning processes;
2. design and implement appropriate research methods taking full account of the range of alternative techniques and approaches;
3. collect, assess and interpret relevant information;
4. draw scientifically founded conclusions that consider social, scientific and ethical insights;
5. apply their knowledge and understanding to a context of their choice;
6. develop, formulate and advance solutions to problems and arguments in their subject area, and defend these through argument;
7. discuss information, ideas, problems and solutions with specialists and non-specialists.

Usability and Relationship to other Modules

- 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 acquire additional skills independently as and if required.

Examination Type: Module Component Examinations

Module Component 1: Thesis
Assessment type: Thesis
Scope: All intended learning outcomes, mainly 1-6.

Length: approx. 6.000 – 8.000 words (15 – 25 pages), excluding front and back matter.
Weight: 80%

Module Component 2: Seminar
Assessment type: Presentation
Duration: approx. 15 to 30 minutes
Weight: 20%

Scope: The presentation focuses mainly on ILOs 6 and 7, but by nature of these ILOs it also touches on the others.

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

Two separate assessments are justified by the size of this module and the fact that the justification of solutions to problems and arguments (ILO 6) and discussion (ILO 7) should at least have verbal elements. The weights of the types of assessments are commensurate with the sizes of the respective module components.

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-09</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-09</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

• Lectures (35 hours)
• Private study (90 hours)</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</td></tr>
</table>

- Vector spaces, linear independence, bases, coordinates
- Linear maps, matrices and their algebra, matrix inverses
- 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

<table>
<tr><td colspan="2">Module Name
Matrix Algebra and Advanced Calculus II</td><td>Module Code
CTMS-MAT-10</td><td>Level (type)
Year 1
(Methods)</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>CTMS-10</td><td colspan="2">Matrix Algebra and Advanced Calculus II</td><td>Lecture</td><td>5</td></tr>
<tr><td>Module Coordinator

Dr. Keivan Mallahi Karai</td><td colspan="2">Program Affiliation
CONSTRUCTOR Track Area</td><td colspan="2">Mandatory Status

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

Pre-requisites: ☒ Matrix Algebra and Advanced Calculus I
Co-requisites: ☒ none
Knowledge, Abilities, or Skills: None beyond formal pre-requisites</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="5">Recommendations for Preparation

Review the content of Matrix Algebra and Advanced Calculus I</td></tr>
<tr><td colspan="5">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
</td></tr>
<tr><td colspan="5">Intended Learning Outcomes

Upon completion of this module, students will be able to
understand the definitions of continuity, derivative of a function as a linear transformation, multivariable integrals, eigenvalues and eigenvectors and associated notions.
apply the methods described in the content section of this module description to the extent that they can
evaluate multivariable integrals using definitions or by applying Green and Stokes theorem.
evaluate various decompositions of matrices
solve standard text-book problems reliably and with confidence;
recognize the mathematical structures in an unfamiliar context and translate them into a mathematical problem statement;
</td></tr>
</table>

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

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

<table>
<tr><td colspan="3">Module Name
Probability and Random Processes</td><td>Module Code
CTMS-MAT-12</td><td>Level (type)
Year 2
(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-12</td><td colspan="3">Probability and random processes</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 CS, SDT, ECE, MMDA, PHDS and RIS</td></tr>
<tr><td colspan="3" rowspan="2">Entry Requirements

Pre-requisites | Co-requisites | Knowledge, Abilities, or Skills

☒ 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.</td><td>Frequency

Annually (Fall)</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

Review all of the first-year calculus and linear algebra modules as indicated in “Entry Requirements – Knowledge, Ability, or Skills” above.</td></tr>
</table>

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

<table>
<tr><td colspan="2">Module Name
Statistics and Data Analytics</td><td>Module Code
CTMS-MET-21</td><td>Level (type)
Year 2
(Methods)</td><td>CP
5</td></tr>
<tr><td colspan="5">Module Components

Number</td></tr>
<tr><td>CTMS-21</td><td colspan="2">Statistics and Data Analytics</td><td>Lecture</td><td>5</td></tr>
<tr><td>Module Coordinator

Dr. Ivan Ovsyannikov</td><td colspan="2">Program Affiliation

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

Mandatory for SDT, MMDA and PHDS</td></tr>
<tr><td colspan="2" rowspan="2">Entry Requirements

Pre-requisites: ☒ Probability and Random Processes
Co-requisites: ☒ none
Knowledge, Abilities, or Skills: • Good command of basic probability</td><td>Frequency

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

• Lectures (35 hours)
• Private Study (105 hours)</td></tr>
<tr><td>Duration
1 semester</td><td colspan="2">Workload

120 hours</td></tr>
<tr><td colspan="5">Recommendations for Preparation

Recap Probability and Random Processes</td></tr>
</table>

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: 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)

<table>
<tr><td colspan="3">Module Name
Logic (perspective I)</td><td>Module Code
CTNS-NSK-01</td><td>Level (type)
Year 2
(New Skills)</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>CTNS-01</td><td colspan="3">Logic (perspective I)</td><td>Lecture (online)</td><td>2.5</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 elective for all UG students (one perspective must be chosen)</td></tr>
<tr><td colspan="3" rowspan="2">Entry Requirements

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

Annually
(Fall)</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="6">Recommendations for Preparation</td></tr>
</table>

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)

<table>
<tr><td colspan="2">Module Name
Logic (perspective II)</td><td>Module Code
CTNS-NSK-02</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-02</td><td colspan="2">Logic (perspective II)</td><td>Lecture (online)</td><td>2.5</td></tr>
<tr><td>Module Coordinator

NN</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
(Fall)</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>
</table>

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: 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>
</table>

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, 87istoryy 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 a causal 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 a correlation 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 counterfactual.

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: 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)

<table>
<tr><td>Module Name

Causation and Correlation (perspective II)</td><td>Module Code

CTNS-NSK-04</td><td>Level (type)

Year 2
(New Skills)</td><td>CP

2.5</td></tr>
<tr><td colspan="4">Module Components</td></tr>
<tr><td>Number</td><td>Name</td><td>Type</td><td>CP</td></tr>
<tr><td>CTNS-04</td><td>Causation and Correlations (perspective II)</td><td>Lecture (online)</td><td>2.5</td></tr>
<tr><td>Module Coordinator

Dr. Keivan Mallahi-Karai, Dr. Eoin Ryan, Dr. Irina Chiaburu</td><td colspan="2">Program Affiliation

• CONSTRUCTOR Track Area</td><td>Mandatory Status

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

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

Annually

(Spring)</td><td>Forms of Learning and Teaching

Online lecture (17.5h)

Private study (45h</td></tr>
<tr><td colspan="2"></td><td>Duration

1 semester</td><td>Workload

62.5 hours</td></tr>
<tr><td colspan="4">Recommendations for Preparation</td></tr>
</table>

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 wil 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: 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: 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	Program Affiliation	Mandatory Status
Marco Verweij	• CONSTRUCTOR Track Area	Mandatory elective

Entry Requirements

Pre-requisites	Co-requisites	Knowledge, Abilities, or Skills
Logic Causation & Correlation	☒ none	• Being able to read primary academic literature • Willingness to engage in teamwork

Frequency	Forms of Learning and Teaching
Annually (Fall)	Online Lectures (35h) Private Study (90h)

Duration	Workload
1 semester	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)

<table>
<tr><td colspan="3">Module Name

Argumentation, Data Visualization and Communication (perspective I)</td><td>Module Code
CTNS-NSK-07</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-07</td><td colspan="3">Argumentation, Data Visualization and Communication (perspective I)</td><td>Lecture (online)</td><td>5</td></tr>
<tr><td>Module Coordinator

Prof. Dr. Jules Coleman,
Prof. Dr. Arvid Kappas</td><td colspan="3">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="3" rowspan="2">Entry Requirements

Pre-requisites: Logic
Causation & Correlation

Co-requisites: ☒ none

Knowledge, Abilities, or Skills</td><td>Frequency

Annually
(Fall)</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

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

Content and Educational aim

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="3">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="6">Module Components</td></tr>
<tr><td>Number</td><td colspan="3">Name</td><td>Type</td><td>CP</td></tr>
<tr><td>CTNS-08</td><td colspan="3">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="3">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 rowspan="2">Entry Requirements

Pre-requisites

Logic

Causation & Correlation</td><td rowspan="2">

Co-requisites

☒ none</td><td rowspan="2">

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)</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)</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
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

Module Name Agency, Leadership, and Accountability			Module Code CTNS-NSK-09	Level (type) Year 3 (New Skills)	CP 5
Module Components					
Number	Name			Type	CP
CTNS-09	Agency, Leadership, and Accountability			Lecture (online)	5
Module Coordinator Prof. Dr. Jules Coleman	**Program Affiliation** • CONSTRUCTOR Track Area			**Mandatory Status** Mandatory elective	
Entry Requirements Pre-requisites ☒ none	Co-requisites ☒ none	Knowledge, Abilities, or Skills	**Frequency** Annually (Spring)	**Forms of Learning and Teaching** Online Lectures (35h) Private Study (90h)	
			Duration	**Workload** 125 hours	
Recommendations for Preparation					
Content and Educational Aims					

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: 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	CTNS-CIP-10	Year 3 (New Skills)	5

Module Components

Number	Name	Type	CP
CTNS-10	Community Impact Project	Project	5

Module Coordinator	Program Affiliation	Mandatory Status
CIP Faculty Coordinator	• CONSTRUCTOR Track Area	Mandatory elective

Entry Requirements

Pre-requisites	Co-requisites	Knowledge, Abilities, or Skills	Frequency	Forms of Learning and Teaching
☒ at least 15 CP from CORE modules in the major	☒ None	• Basic knowledge of the main concepts and methodological instruments of the respective disciplines	Annually (Fall / Spring)	• Introductory, accompanying, and final events: 10 hours • Self-organized teamwork and/or practical work in the community: 115 hours

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 as socially conscious and responsible graduates (part of the Constructor 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

- understand the real-life issues of communities, organizations, and industries and relate them to concepts in their own discipline;
- enhance problem-solving skills and develop critical faculty, create solutions to problems, and communicate these solutions appropriately to their audience;

- apply media and communication skills in diverse and non-peer social contexts;
- develop an awareness of the societal relevance of their own scientific actions and a sense of social responsibility for their social surroundings;
- reflect on their own behavior critically in relation to social expectations and consequences;
- work in a team and deal with diversity, develop cooperation and conflict skills, and strengthen their empathy and tolerance for ambiguity.

Indicative Literature

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 Assessment, 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 to Philosophical Ethics

<table>
<tr><td colspan="3">Module Name

Introduction to Philosophical Ethics</td><td>Module Code
CTHU-HUM-001</td><td>Level (type)
Year 1</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>CTHU-001</td><td colspan="3">Introduction to Philosophical Ethics</td><td>Lecture (online)</td><td>2.5</td></tr>
<tr><td>Module Coordinator

Dr. Eoin Ryan</td><td colspan="3">Program Affiliation

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

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

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

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

Online lectures (17.5 h)
Private Study (45h)</td></tr>
<tr><td>Duration

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

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

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		**Module Code**	**Level (type)**	**CP**
Introduction to the Philosophy of Science		CTHU-HUM-002	Year 1	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 Pre-requisites: ☒ none Co-requisites: ☒ none Knowledge, Abilities, or Skills		**Frequency** Annually (Spring)	**Forms of Learning and Teaching** Online lectures (17.5h) Private Study (45h)	
		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

<table>
<tr><td colspan="3">Module Name
Introduction to Visual Culture</td><td>Module Code
CTHU-HUM-003</td><td>Level (type)
Year 1</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>CTHU-003</td><td colspan="3">Introduction to Visual Culture</td><td>Lecture (online)</td><td>2.5</td></tr>
<tr><td>Module Coordinator

Irina Chiaburu</td><td colspan="3">Program Affiliation
Constructor Track Area</td><td colspan="2">Mandatory Status

Mandatory elective</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/Fall)</td><td colspan="2">Forms of Learning and Teaching

Online Lecture</td></tr>
<tr><td>Duration

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

62.5 h</td></tr>
<tr><td colspan="6">Recommendations for Preparation</td></tr>
<tr><td colspan="6">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.</td></tr>
<tr><td colspan="6">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</td></tr>
<tr><td colspan="6">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.</td></tr>
</table>

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

Mathematics, Modeling and Data Analytics BSc					Analysis	Linear Algebra	Programming in Python and C++	Mathematical Modeling	Core Algorithms & Data Structures	Algorithms and Data Structures	Number Theory	Dicrete Mathematics	Computational Modeling	Algebra	Real Analysis	Complex Analyis	Scientific Data Analysis	Machine Learning	Specialization Modules	Bachelor Thesis and Seminar	Internship	CT Methods	CT New Skills	CT German Langauge and Humanities
Semester					1	2	1	2	2	2	3	4	3/4	3	4	3	3	4	4-6	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	me	m	m	m	me	me
Credits					7.5	7.5	7.5	7.5	7.5	7.5	5	5	5	5	5	5	5	5	5	15	15	20	20	5
	Competencies*																							
Program Learning Outcomes	**A**	**E**	**P**	**S**																				
Make rigorous mathematical arguments and understand the concept of mathematical proof	x	x	x		x	x		x	x		x	x	x	x	x	x	x	x	x	x				
Recognize patterns and discover underlying principles	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				
Confidently apply the methods in the core fields of pure and applied mathematics (Analysis, Linear Algebra, Numerical Analysis, Probability, Topology, Geometry) at a level allowing easy transition into top graduate schools around the world	x	x			x	x		x	x		x	x	x	x	x	x	x	x	x	x				
Create mathematical models for a wide range of real-world problems	x	x						x	x	x									x					
Perform statistical analysis, machine learning algorithms, and visualize data	x	x						x	x	x			x											
Solve mathematical problems, independently analyze mathematical proofs, and present them coherently	x	x			x	x		x			x	x	x	x	x	x			x					
Understand and be able to apply the key concepts in two or more of the following, at the level of a first advanced undergraduate course: Complex Analysis, Algebra, Ordinary Differential Equations, Partial Differential Equations, Number Theory, Stochastic Processes, Nonlinear Dynamics, Discrete Mathematics	x	x															x	x	x					
The ability to write simple programs in at least one programming language	x	x			x	x	x		x	x												x		
Knowledge in mathematical modeling and their application to everyday problems	x	x						x	x	x							x							
Ability to formulate mathematical ideas in written text	x	x			(x)	(x)		(x)			(x)	(x)	(x)	(x)	(x)	(x)				x				
Ability to present mathematical ideas to others	x	x	x	x	x	x														x	x			
Think analytically	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	(x)	(x)	(x)	(x)
Present complex ideas to specialists and non-specialists	x	x	x	x	x	x														x	x	x	x	x
Are confident in acquiring, understanding, and organizing information	x	x	x		(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)		x	x	x	x	x
Possess generic problem solving skills, including a sense of determining what is already known, what is not known, and what is required to obtain a solution	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x
Demonstrate a sense for the use of Mathematics in one or more fields of application	x	x						x					x				x	x		x			x	
Engage ethically with academic and professional communities, and with the general public to actively contribute to a sustainable future, reflecting and respecting different views		x	x	x																x	x	x	x	x
Demonstrate a sense for the use of Mathematics in one or more fields of application	x	x	x	x	x	x	x	x				x	x				x	x	x	x				
Engage ethically with academic and professional communities, and with the general public to actively contribute to a sustainable future, reflecting and respecting different views	x	x	x	x																	x			
Take responsibility for their own learning, personal and professional development and role in society, evaluating critical feedback and self-analysis		x	x	x	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)	(x)
Take on responsibility in a diverse team				x																	x		x	(x)
Adhere to and defend ethical, scientific and professional standards	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Assessment Type																								
Oral examination																								
Written examination					x	x	x	x	x	x	x	x		x	x	x		x	x			x	x	x
Project Assessment													x						x				x	
Project Report																					x			
Essay																								
Laboratory report																								
Poster presentation																								
Portfolio																	x		x					
Presentation																				x			x	
Thesis																				x				
Other							x	x	x															x
Module achievements																			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