JACOBS UNIVERSITY

Study Program Handbook

Mathematics

Bachelor of Science

Subject-specific Examination Regulations for Mathematics (Fachspezifische Prüfungsordnung)

The subject-specific examination regulations for Mathematics 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 6 of this handbook).

Version	Valid as of	Decision	Details
Fall 2019 – V1.2	Sep 01, 2019	Approved by Academic Senate on June 26, 2019	V1Master version V1.1 Editorial changes, indicative literature V1.2 BQ-Area updated

Contents

1 Program Overview

1.1 Concept

1.1.1 The Jacobs University Educational Concept

Jacobs University aims to educate students for both an academic and a professional career by emphasizing four core objectives: academic quality, self-development/personal growth, internationality and the ability to succeed in the working world (employability). Hence, study programs at Jacobs University offer a comprehensive, structured approach 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.

In this context, it is Jacobs 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 Jacobs 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 and the minor option provide breadth while the university-wide general foundation and methods modules, mandatory German language requirements, 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, Jacobs University offers professional advising and counseling.

Jacobs 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 in 2018. 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

Why study Mathematics?

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

- mathematics offers a great variety of academic career paths, ranging from teaching at all levels to research in mathematics and its adjacent fields;

- a bachelor's degree in mathematics qualifies students for graduate study not only in Mathematics, but also in neighboring disciplines such as Engineering, Physics, Astronomy, Economics, Finance, MBA programs, and many others;
- mathematicians find 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 at Jacobs 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 achieve, or even identify, their personal goals. In this spirit, the Bachelor Program in Mathematics at Jacobs 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.

1.2.1 Qualification Aims

The program aims at a broad general education in Mathematics where a high level of mathematical rigor and depth is connected with challenges from contemporary applied contexts. As a result, 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 in Mathematics.

The detailed overarching program aims are

- comprehensive basic education in the core fields of pure and applied mathematics;
- optionally teach the core principles of scientific computing and/or financial mathematics;
- encourage interdisciplinarity, specifically supported by the option to achieve a minor in a different field of study;
- 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;
- provide a strong set of career-enhancing skills;
- 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.

1.2.2 Intended Learning Outcomes

By the end of the program, students will possess the following Mathematical Skills. They will be able to

- make rigorous mathematical arguments and understand the concept of mathematical proof;
- recognize patterns and discover underlying principles;
- 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;
- independently perform simple proofs and derivations in these fields and know the principles behind more complicated proofs and derivations;
- 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.

Graduates possess the following Practical Skills:

- the ability to write simple programs in at least one programming language;
- a basic knowledge about standard mathematical software packages and use them productively in everyday problem solving;
- can formulate mathematical ideas in written text;
- can present mathematical ideas to others.

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

- think analytically;
- present complex ideas to specialists and non-specialists;
- are confident in acquiring, understanding, and organizing information;
- 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;
- 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

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

1.3 Career Options

There are few undergraduate degrees that rival mathematics in the diversity of rewarding job options, which include the following:

- 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 Services Center (CSC) as well as the Jacobs Alumni Office help students in their career development. The CSC 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 their time at Jacobs University. Furthermore, the Alumni Office helps students establish a long-lasting and global network which is useful when exploring job options in academia, industry, and elsewhere.

1.4 Admission Requirements

Admission to Jacobs 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 Jacobs 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
- Official or certified copies of high school/university transcripts
- Educational History Form
- Standardized test results (SAT/ACT/TestAS) if applicable
- ZeeMee electronic resume (optional)
- Language proficiency test results (TOEFL, IELTS or equivalent)

German language proficiency is not required, instead all applicants need to submit proof of English proficiency.

For any student who has acquired the right to study at a university in the country where she/he has acquired the higher education entrance qualification Jacobs University accepts the common international university entrance tests as a replacement of the entrance examination. Applicants who have a subject-related entrance qualification (fachgebundene Hochschulreife) may be admitted only to respective studies programs.

For more detailed information about the admission visit: https://www.jacobs-university.de/study/undergraduate/application-information

1.5 More Information and Contact

Dr. Marcel Oliver

Professor of Mathematics

Email: m.oliver@jacobs-university.de

Telephone: +49 421 200 32 12

or visit our program website: http://math.jacobs-university.de/undergraduate/

2 The Curricular Structure

2.1 General

The curricular structure provides multiple elements for enhancing employability, interdisciplinarity, and internationality. The unique Jacobs 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 Jacobs University are based on a coherently modularized structure, which provides students with an extensive and flexible choice of study plans to meet the educational aims of their major as well as minor study interests and complete their studies within the regular period.

The framework policies and procedures regulating undergraduate study programs at Jacobs University can be found on the website (https://www.jacobs-university.de/academic-policies).

2.2 The Jacobs University 3C Model

Jacobs 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 under-graduate 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 3C-Model - that groups the disciplinary content of the three study years according to overarching themes:

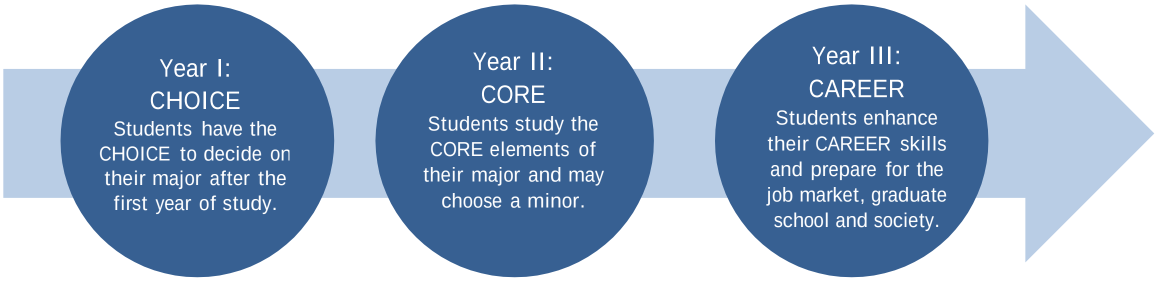


Figure 1: The Jacobs University 3C-Model

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 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 15-30 CP will be from their intended major. A unique feature of our curriculum structure allows students to select their major freely upon entering Jacobs University. The Academic Advising Coordinator offers curricular counseling to all Bachelor students independently of their major, while Academic Advisors support students in their decision-making regarding their major study program as contact persons from the faculty.

To pursue Mathematics as a major, the following CHOICE modules (22.5 CP) need to be taken as mandatory modules:

- CHOICE Module: Analysis I (7.5 CP, Semester 1)
- CHOICE Module: Linear Algebra (7.5 CP, Semester 2)
- CHOICE Module Applied Mathematics (7.5 CP, Semester 2)

These modules cover the foundations of Calculus and Linear Algebra from a rigorous mathematical perspective ("Analysis I" and "Linear Algebra"). In addition, the module "Applied Mathematics" covers theory and the applications of multi-variable calculus. These three CHOICE modules complement the Methods modules ("Calculus and Elements of Linear Algebra I + II") which Mathematics students must also take in their first year of study, see Section 2.3.1.

The remaining CHOICE modules (22.5 CP) can be selected in the first year of study according to interest and with the aim of allowing a change of major until the beginning of the second year, when the major choice becomes fixed (see 2.2.1.1 below).

2.2.1.1 Major Change Option

Students can still change to another major at their beginning of the second year of studies if they have taken the corresponding mandatory CHOICE modules in their first year of studies. All students must participate in a seminar on the major change options in the O-Week and consult their Academic Advisor in the first year of studies prior to changing their major.

Math students who would like to retain an option for a major change are strongly recommended to register for the CHOICE modules of one of the following study programs in their first year. The module descriptions can be found in the respective Study Program Handbook.

- Earth and Environmental Studies (EES)
  CHOICE Module: General Earth and Environmental Sciences (7.5 CP)
  CHOICE Module: General Geology (7.5 CP)

- Physics (Phys)
  CHOICE Module: Classical Physics (7.5 CP)
  CHOICE Module: Modern Physics (7.5 CP)

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

- Integrated Social Sciences (ISS)
  CHOICE Module: Introduction to the Social Sciences 1: Politics and Society (7.5CP)
  CHOICE Module: Introduction to the Social Sciences 2: Media and Society (7.5 CP)

- Psychology

CHOICE Module: Essentials of Cognitive Psychology (7.5 CP)
CHOICE Module: Essentials of Social Psychology (7.5 CP)

A change of major after the first year of study between Mathematics and majors that are not listed here are not possible within the default study plans. Students considering a change-of-major option between Mathematics and a major not listed here are advised to consult with faculty of both majors as early as possible; individual solutions are often possible.

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 and skills 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 as a major, 20 CP mandatory CORE modules need to be acquired:

- CORE Module: Undergraduate Seminar (5 CP, Semester 3 and 4)
- CORE Module: Introductory Algebra (7.5 CP, Semester 3)
- CORE Module: Analysis III (7.5 CP, Semester 4)

Students complement their studies by taking 25 ECTS of the second/third year CORE and Specialization modules[1]:

- CORE Module: Discrete Mathematics (5CP)
- CORE Module: Number Theory (5CP)
- Specialization: (A) Complex Analysis (5 CP)
- Specialization: (B) Real Analysis (5 CP)
- Specialization: (A) Topology (5 CP)
- Specialization: (B) Foundations of Mathematical Physics (5 CP)
- Specialization: (A) Applied Dynamical Systems Lab (7.5 CP)
- Specialization: (B) Stochastic Methods Lab (7.5 CP)
- Specialization: (A) Partial Differential Equations (5 CP)
- Specialization: (B) Dynamical Systems Lab (5 CP)
- Specialization: (A) Algebra (5 CP)
- Specialization: (B) Algebraic Topology (5 CP)
- Specialization: (A) Stochastic Processes (5 CP)
- Specialization: (B) Numerical Analysis (5 CP)

or substitute a total of 15 CP of the listed modules with CORE modules from a second field of study according to interest and/or with the aim to pursue a minor.

[1] Each of the listed specialization modules is offered biennially; the letter A in the Study and Examination Plan refers to odd-numbered calendar years and the letter B refers to even-numbered calendar years."

2.2.2.1 Minor Option

Mathematics students can take CORE modules (or more advanced Specialization modules) from a second discipline, which allows them to incorporate a minor study track into their undergraduate education, within the 180 CP required for a bachelor's degree. The educational aims of a minor are to broaden students' knowledge and skills, support a critical reflection of statements in complex contexts, foster an interdisciplinary approach to problem-solving, and to develop an individual academic and professional profile in line with students' strengths and interests. This extra qualification will be highlighted in the transcript.

The Academic Advising Coordinator, Academic Advisor, and the Study Program Chair of the minor study program support students in the realization of their minor selection; the consultation with the Academic Advisor is mandatory when choosing a minor.

As a rule, this requires Mathematics students to:

- select CHOICE modules (15 CP) from the desired minor program in the first year;
- substitute a total of 15 CP of the mandatory elective CORE modules and Specialization modules in the second year with the default minor CORE modules of the minor study program.

The requirements for each specific minor are described in the handbook of the study program offering the minor (Chapter 3.2) and are marked in the respective Study and Examination Plans. For an overview of accessible minors, please check the Major/Minor Combination Matrix which is published at the beginning of each academic year.

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 students to take specialization modules within their discipline, but also focuses on the responsibility of students beyond their discipline (see Jacobs Track).

The 5th semester opens also 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 Jacobs University's employability approach students are required to 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 of their business plans.

For further information, please contact the Career Services Center (https://www.jacobs-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. The default specialization module size is 5 CP, with smaller 2.5 CP modules being possible as justified exceptions.

To pursue Mathematics as a major, students take further 15 CP from mandatory elective Specialization modules[2]

- Specialization: (A) Complex Analysis (5 CP)
- Specialization: (B) Real Analysis (5 CP)
- Specialization: (A) Topology (5 CP)
- Specialization: (B) Foundations of Mathematical Physics (5 CP)
- Specialization: (A) Applied Dynamical Systems Lab (7.5 CP)
- Specialization: (B) Stochastic Methods Lab (7.5 CP)
- Specialization: (A) Partial Differential Equations (5 CP)
- Specialization: (B) Dynamical Systems Lab (5 CP)
- Specialization: (A) Algebra (5 CP)
- Specialization: (B) Algebraic Topology (5 CP)
- Specialization: (A) Stochastic Processes (5 CP)
- Specialization: (B) Numerical Analysis (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 Jacobs University study abroad procedures. Several exchange programs allow students to directly enroll at prestigious partner institutions worldwide. Jacobs 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 Office (https://www.jacobs-university.de/study/international-office).

Mathematics 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

[2] Each of the listed specialization modules is offered biennially; the letter A refers to odd-numbered calendar years and the letter B refers to even-numbered calendar years."

between 10-15 CP of major-specific Specialization modules and between 5-15 CP of modules equivalent to the non-disciplinary Big Questions modules or the Community Impact Project (see Jacobs 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 Big Questions modules to reach 15 CP in this area. Study abroad students are allowed to substitute the 5 CP Community Impact Project (see Jacobs Track below) with 5 CP of Big Questions

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 Jacobs faculty member: the Bachelor Thesis (12 CP) and a Seminar (3 CP). The title of the thesis will appear on the students' transcripts.

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

With their Bachelor Thesis students demonstrate mastery of the contents and methods of their major-specific research field. Furthermore, students show the ability to analyze and solve a well-defined problem with scientific approaches, a critical reflection of the status quo in scientific literature, and the original development of their own ideas. With the permission of a Jacobs 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.

2.3 The Jacobs Track

The Jacobs Track, an integral part of all undergraduate study programs, is another important feature of Jacobs University's educational model. The Jacobs Track runs parallel to the disciplinary CHOICE, CORE, and CAREER modules across all study years and is an integral part of all undergraduate study programs. It reflects a university-wide commitment to an in-depth training in scientific methods, fosters an interdisciplinary approach, raises awareness of global challenges and societal responsibility, enhances employability, and equips students with augmented skills desirable in the general field of study. Additionally, it integrates (German) language and culture modules.

2.3.1 Methods and Skills Modules

Methods and skills 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 and Skills area in their curriculum. The modules that are specifically assigned to each study programs 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 and Skills area. The size of all Methods and Skills modules is 5 CP.

To pursue Mathematics as major, the following Methods and Skills modules (20 CP) need to be taken as mandatory modules:

- Methods: Calculus and Elements of Linear Algebra I (5 CP)
- Methods: Calculus and Elements of Linear Algebra II (5 CP)
- Methods: Probability and Random Processes (5 CP)
- Methods: Numerical Methods (5 CP)

2.3.2 Big Questions Modules

The modules in the Big Questions area (10 CP) intend to broaden students' horizons with applied problem solving between and beyond their chosen disciplines. The offerings in this area comprise problem-solving oriented modules that tackle global challenges from the perspectives of different disciplinary backgrounds that allow, in particular, a reflection of acquired disciplinary knowledge in economic, societal, technological, and/or ecological contexts. Working together with students from different disciplines and cultural backgrounds, these modules cross the boundaries of traditional academic disciplines.

Students are required to take 10 CP from modules in the Area. This curricular component is offered as a portfolio of modules, from which students can make free selections during their 5th and 6th semester with the aim of being exposed to the full spectrum of economic, societal, technological, and/or ecological contexts. The size of Big Questions Modules is either 2.5 or 5 CP.

2.3.3 Community Impact Project

In their 5th semester students are required to take a 5 CP Community Impact Project (CIP) module. Students engage in on-campus or off-campus activities that challenge their social responsibility, i.e., they typically work on major-related projects that make a difference in the community life on campus, in the campus neighborhood, Bremen, or on a cross-regional level. The project is supervised by a faculty coordinator and mentors.

Study abroad students are allowed to substitute the 5-CP Community Impact Project with 5 CP of Big Questions modules.

2.3.4 Language Modules

Communication skills and foreign language abilities foster students' intercultural awareness and enhance their employability in an increasingly globalized and interconnected world. Jacobs University supports its students in acquiring and improving these skills by offering a variety of language modules at all proficiency levels. Emphasis is put on fostering the German language skills of international students as they are an important prerequisite for non-native students to learn about, explore, and eventually integrate into their host country and its professional environment. Students who meet the required German proficiency level (e.g., native speakers) are required to select modules in any other modern foreign language offered (Chinese, French or Spanish). Hence, acquiring 10 CP in language modules, with German mandatory for non-native speakers, is a requirement for all students. This curricular component is offered as a four-semester sequence of foreign language modules. The size of the Language Modules is 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, IMS, and ECE, 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 Jacobs 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

- understand what constitutes a proof, distinguish heuristics from rigorous arguments, and find gaps in a chain of reasoning;
- make rigorous mathematics arguments in Linear Algebra and Analysis, the two central subject areas in a structured mathematics curriculum;
- understand the key concepts in at least two areas of mathematics, pure or applied, at a more advanced level;
- solve basic problems by applying the standard methods in these fields,
- recognize mathematical structures and formalize descriptions of concepts presented in common language;
- 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 default 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 I (7.5 CP)

- CHOICE Module: Advanced Linear Algebra (7.5 CP)

The remaining 15 CP of can be selected among all second- and third-year Mathematics CORE and Specialization modules.

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

- Methods Module: Calculus and Elements of Linear Algebra I (5 CP)
- Methods Module: Calculus and Elements of Linear Algebra II (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 Undergraduate Program Regulations

4.1 Scope of these Regulations

The regulations in this handbook are valid for all students who entered the Mathematics undergraduate program at Jacobs University in Fall 2019. In the case of a conflict between the regulations in this handbook and the general Policies for Bachelor Studies, the latter applies (see http://www.jacobs-university.de/academic-policies).

In exceptional cases, certain necessary deviations from the regulations of this study handbook might occur during the course of study (e.g., change of the semester sequence, assessment type, or the teaching mode of courses). Jacobs University Bremen reserves therefore the right to modify the regulations of the program handbook.

4.2 Degree

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

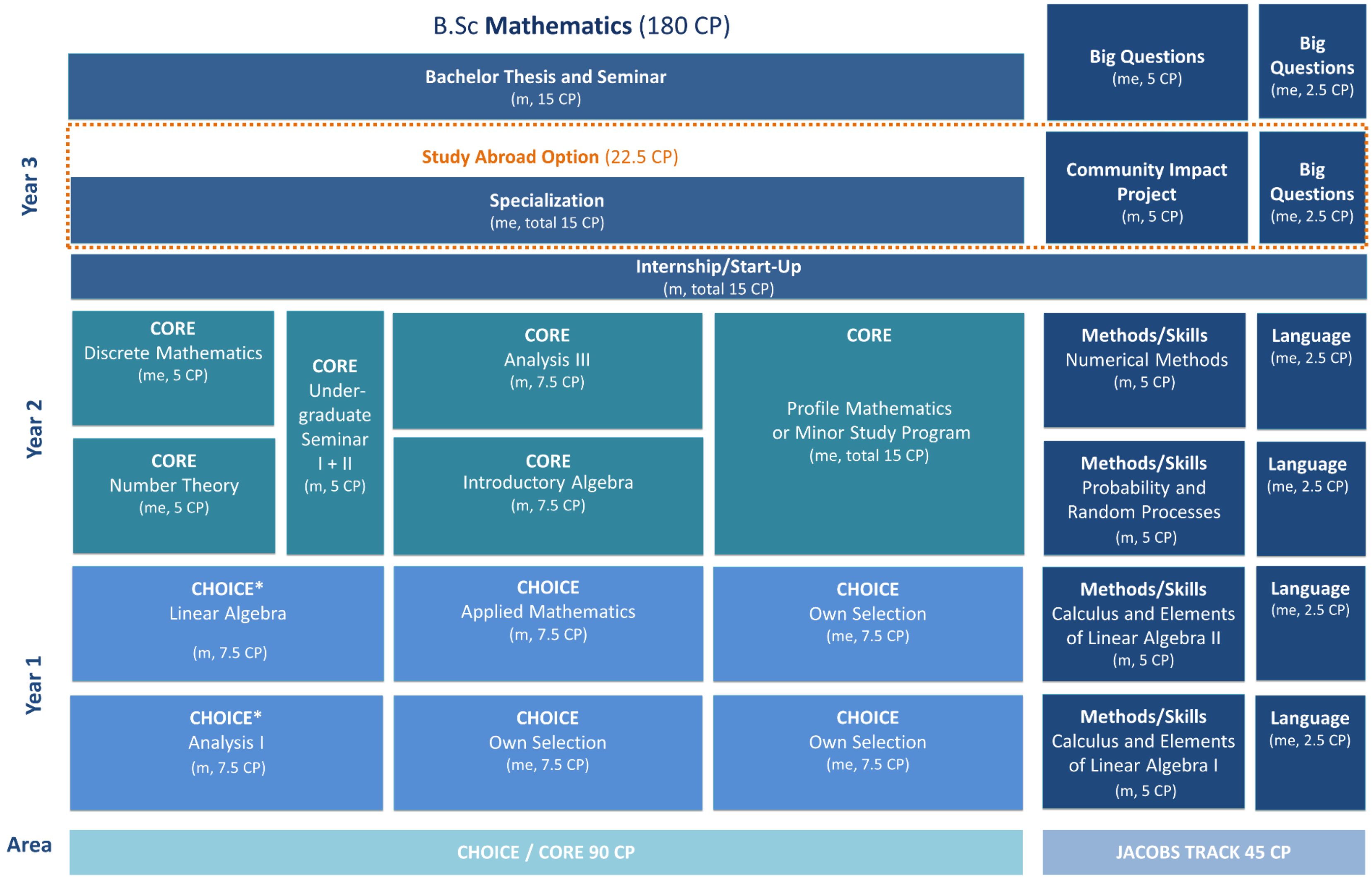
4.3 Graduation Requirements

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

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



* mandatory for minor students (default minor)
m = mandatory
me = mandatory elective

Figure 2: Schematic Study Plan for Mathematics

Mathematics BSc

Matriculation Fall 2019

	Program-Specific Modules	Type	Assessment	Period	Status¹	Sem.	CP
Year 1 - CHOICE							**45**
Take the mandatory CHOICE modules listed below, this is a requirement for the Math program.							
	Unit: Foundations of Mathematics (default minor)						**15**
CH-200	**Module: Analysis I** (default minor)				**m**	**1**	**7.5**
CH-200-A	Analysis I	Lecture	Written examination	Examination period			5
CH-200-B	Tutorial Analysis I	Tutorial					2.5
CH-201	**Module: Linear Algebra** (default minor)				**m**	**2**	**7.5**
CH-201-A	Linear Algebra	Lecture	Written examination	Examination period			5
CH-201-B	Tutorial Linear Algebra	Tutorial					2.5
	Unit: Applied Mathematics						**7.5**
CH-202	**Module: Applied Mathematics**				**m**	**2**	**7.5**
CH-202-A	Advanced Calculus	Lecture	Written examination	Examination period			5
CH-202-B	Numerical Software Lab	Lab	Lab report				2.5
	Unit: CHOICE (own selection)				**me**	**1/2**	**22.5**
Students take three further CHOICE modules (22.5 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**				**me**	**3**	**5**
CO-500-A	Number Theory	Lecture	Written examination	Examination period			5
CO-501	**Module: Discrete Mathematics**				**me**	**4**	**5**
CO-501-A	Discrete Mathematics	Lecture	Written examination	Examination period			5
CO-502	**Module: Undergraduate Seminar**				**m**	**3+4**	**5**
CO-502-A	Undergraduate Seminar I	Seminar	Presentation	During the semester		3	2.5
CO-502-B	Undergraduate Seminar II	Seminar				4	2.5
	Unit: Core Mathematics						**15**
CO-503	**Module: Introductory Algebra**				**m**	**3**	**7,5**
CO-503-A	Introductory Algebra	Lecture	Written examination	Examination period			5
CO-503-B	Tutorial Introductory Algebra	Tutorial					2.5
CO-504	**Module: Analysis III**				**m**	**4**	**7,5**
CO-504-A	Analysis III	Lecture	Written examination	Examination period			5
CO-504-B	Tutorial Analysis III	Tutorial					2.5
	Unit: Profile Mathematics or Minor Study Program				**me**	**3+4**	**15**
Take 15 CP of Mathematics Specialization modules or substitute Specialization modules to pursue a minor							
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		Report / Business Plan	During the 5th semester			15
CA-MATH-800	**Module: Seminar / Thesis Mathematics**				**m**	**6**	**15**
CA-MATH-800-T	Thesis Math	Thesis	Thesis	15th of May			12
CA-MATH-800-S	Thesis Seminar Math	Seminar	Presentation	During the semester			3
	Unit: Specialization Mathematics				**me**	**5+6**	**15**
Take a total of 15 CP of specialization modules.³							
CA-S-MATH-802 / 801	Module Rotation: Complex Analysis (A) – Real Analysis (B)	Lecture	Written examination	Examination period		3/5	5
CA-S-MATH-809 / 806	Module Rotation: Topology (A) – Foundations of Mathematical Physics (B)	Lecture	Written examination	Examination period		3/5	5
CA-S-MATH-810 / 811	Module Rotation: Applied Dynamical Systems Lab (A) – Stochastic Methods Lab (B)	Lecture	Project	During the semester		3/5	7.5
CA-S-MATH-807 / 805	Module Rotation: Partial Differential Equations (A) – Dynamical Systems (B)	Lecture	Written examination	Examination period		4/6	5
CA-S-MATH-808 / 812	Module Rotation: Algebra (A) – Algebraic Topology (B)	Lecture	Written examination	Examination period		4/6	5
CA-S-MATH-803 / 804	Module Rotation: Stochastic Processes (A) – Numerical Analysis (B)	Lecture	Written examination	Examination period		4/6	5

	Jacobs Track Modules (General Education)	Type	Assessment	Period	Status¹	Sem.	CP
							15
	Unit: Methods / Skills						**10**
JTMS-MAT-09	**Module: Calculus and Elements of Linear Algebra I**				**m**	**1**	**5**
JTMS-09	Calculus and Elements of Linear Algebra I	Lecture	Written examination	Examination period			5
JTMS-MAT-10	**Module: Calculus and Elements of Linear Algebra II**				**m**	**2**	**5**
JTMS-10	Calculus and Elements of Linear Algebra II	Lecture	Written examination	Examination period			5
	Unit: Language						**5**
	German is the default language. Native German speakers take modules in another offered language.						
JTLA	**Module: Language 1**				**m**	**1**	**2.5**
JTLA-xxx	Language 1	Seminar	Various	Various	me		2.5
JTLA	**Module: Language 2**				**m**	**2**	**2.5**
JTLA-xxx	Language 2	Seminar	Various	Various	me		2.5
	Unit: Methods / Skills						**10**
JTMS-MAT-12	**Module: Probability and Random Processes**				**m**	**3**	**5**
JTMS-12	Probability and Random Processes	Lecture	Written examination	Examination period			5
JTMS-MAT-13	**Module: Numerical Methods**				**m**	**4**	**5**
JTMS-13	Numerical Methods	Lecture	Written examination	Examination period			5
	Unit: Language						**5**
	German is default language. Native German speakers take modules in another offered language.						
JTLA	**Module: Language 3**				**m**	**3**	**2.5**
JTLA-xxx	Language 3	Seminar	Various	Various	me		2.5
JTLA	**Module: Language 4**				**m**	**4**	**2.5**
JTLA-xxx	Language 4	Seminar	Various	Various	me		2.5
							15
	Unit: Big Questions						**10**
JTBQ	**Module: Big Questions**				**m**	**5/6**	
Take a total of 10 CP of Big Questions modules with each 2.5 or 5 CP		Lecture	Various	Various	**me**		10
	Unit: Community Impact Project						**5**
JTCI-CI-950	**Module: Community Impact Project**				**m**	**5**	**5**
JTCI-950	Community Impact Project	Project	Project	Examination period			

Total CP **180**

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

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

³ Each of the listed specialization modules is offered biennially; the letter A refers to odd-numbered calendar years, the letter B refers to even-numbered calendar years.

Figure 3: Study and Examination Plan

7 Module Descriptions

7.1 Analysis I

<table>
<tr><td colspan="3">Module Name
Analysis I</td><td>Module Code
CH-200</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-200-A</td><td colspan="3">Analysis I</td><td>Lecture</td><td>5</td></tr>
<tr><td>CH-200-B</td><td colspan="3">Analysis I Tutorial</td><td>Tutorial</td><td>2.5</td></tr>
<tr><td>Module Coordinator

S. Petrat</td><td colspan="3">Program Affiliation

• Mathematics</td><td colspan="2">Mandatory Status

Mandatory for 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>
<tr><td colspan="6">Recommendations for Preparation

• It is recommended to co-enroll in the Methods module “Calculus and Elements of Linear Algebra 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.jacobs-university.de/undergraduate/prepare/index.php</td></tr>
<tr><td colspan="6">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)</td></tr>
</table>

Intended Learning Outcomes

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

- cleanly formulate mathematical concepts and results discussed in class;
- outline proofs which have been given in the lectures ;
- independently prove results which are direct consequences of those proved in the lectures;
- 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 I, third edition. New Delhi: Hindustan Book Agency.

Usability and Relationship to other Modules

- This module is part of the core education in Mathematics.
- Mandatory for a Major in Mathematics
- Mandatory for a Minor in Mathematics
- This module is an elective for students of all other undergraduate studies.
- It is also valuable for students in Physics, Computer Science, IMS, 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 "Calculus and Elements of Linear Algebra I" in the following way: "Calculus and Elements of Linear Algebra I" emphasizes the operational aspects, computational skills, and intuitive understanding, while Analysis I 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.

7.2 Linear Algebra

<table>
<tr><td colspan="3">Module Name
Linear Algebra</td><td>Module Code
CH-201</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-201-A</td><td colspan="3">Linear Algebra</td><td>Lecture</td><td>5</td></tr>
<tr><td>CH-201-B</td><td colspan="3">Linear Algebra</td><td>Tutorial</td><td>2.5</td></tr>
<tr><td>Module Coordinator
I. Penkov</td><td colspan="3">Program Affiliation
• Mathematics</td><td colspan="2">Mandatory Status
Mandatory for Mathematics</td></tr>
<tr><td rowspan="2">Entry Requirements

Pre-requisites
☒ None</td><td rowspan="2">

Co-requisites
☒None</td><td rowspan="2">

Knowledge, Abilities, or Skills
• Basic matrix algebra at the level achieved in “Calculus and Elements of Linear Algebra I”</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>
<tr><td colspan="6">Recommendations for Preparation
• Revise your matrix algebra.
• Unless prepared otherwise, take the Methods module “Calculus and Elements of Linear Algebra I” in the first semester.</td></tr>
<tr><td colspan="6">Content and Educational Aims
This module continues the introduction to Linear Algebra from the methods module “Calculus and Elements of Linear Algebra 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</td></tr>
</table>

Intended Learning Outcomes By the end of the module, students will be able to • describe the concept of a vector space and linear operator in an abstract way • explain the connection of abstract linear algebra in the context of matrix algebra • discuss the proofs of the major theorems from class • illustrate the use of bilinear forms and their role in geometry • 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 • Mandatory for a Major in Mathematics • Mandatory for a Minor in Mathematics • This module is an elective for students of all other undergraduate studies • It is also valuable for students in Physics, Computer Science, IMS, 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 "Calculus and Linear Algebra I and II" in the following way: "Calculus and Linear Algebra 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

7.3 Applied Mathematics

<table>
<tr><td colspan="2">Module Name
Applied Mathematics</td><td colspan="2">Module Code
CH-202</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-202-A</td><td colspan="3">Advanced Calculus and Methods of Mathematical Physics</td><td>Lecture</td><td>5</td></tr>
<tr><td>Ch-202-B</td><td colspan="3">Numerical Software Lab</td><td>Lab</td><td>2.5</td></tr>
<tr><td>Module Coordinator

Marcel Oliver
Ulrich Kleinekathöfer</td><td colspan="3">Program Affiliation

• Mathematics</td><td colspan="2">Mandatory Status

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

Pre-requisites: ☒ None
Co-requisites: ☒ None
Knowledge, Abilities, or Skills:
• Single-variable Calculus at the level achieved in “Calculus and Elements of Linear Algebra I”</td><td>Frequency
Annually
(Spring)</td><td colspan="2">Forms of Learning and Teaching

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

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

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

Recapitulate single variable Calculus at a level of at least “Calculus and Elements of Linear Algebra I”</td></tr>
</table>

Content and Educational Aims

This module covers advanced topics from calculus that are part of the core mathematics education of every Physicist and also forms a fundamental part of the mathematics major. It features examples and applications from the physical sciences. The module is designed to be taken with minimal pre-requisites and is tightly coordinated with the parallel module Calculus and Elements of Linear Algebra II. The style of development strives for rigor, but avoids abstraction and prefers simplicity over generality.

Topics covered include:

- Taylor series, power series, uniform convergence
- Advanced concepts from multivariable differential calculus, here mainly the inverse and implicit function theorem; elementary vector calculus and Lagrange multipliers are covered in Calculus and Elements of Linear Algebra II
- Riemann integration in several variables, and line integrals
- The Gauss and Stokes integral theorems
- Change of variables and integration in polar coordinates
- Fourier integrals and distributions
- Applications to partial differential equations that are important in physics (Laplace, Poisson, diffusion, wave equations)
- Very brief introduction to complex analysis (Cauchy formula and residue theorem)

The lecture part is complemented by a lab course in Numerical Software (Scientific Python), which has become an essential tool for numerical computation and data analysis in many areas of mathematics, physics, and other sciences. Topics include:

- Writing vectorized code using NumPy arrays
- An introduction to SciPy for special functions and black-boxed algorithms (root solvers, quadrature, ODE solvers, and fast Fourier transform)
- Visualization using Matplotlib, including a general introduction to the effective visualization of scientific data and concepts
- The lab also includes a very brief comparative introduction to MATLAB, another standard numerical tool.

Intended Learning Outcomes

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

1. apply series expansions in a variety of mathematical and scientific contexts;
2. solve, simplify, and transform integrals in several dimensions;
3. explain the intuition behind the major theorems;
4. use the major theorems in an application context;
5. compute Fourier transforms and apply them to problems in Calculus and Partial Differential Equations;
6. distinguish differentiability in a complex from a real variable;
7. use numerical software to support simple numerical tasks and to visualize data.

Indicative Literature

S. Kantorovitz (2016). Several Real Variables, Berlin: Springer.

K. Riley, M. Hobson, S. Bence (2006). Mathematical Methods for Physics and Engineering, third edition. Cambridge: Cambridge University Press.

D.J. Pine (2018). Introduction to Python for Science and Engineering. Boca Raton: CRC Press.

Usability and Relationship to other Modules

- This module is a mandatory part of the core education in Mathematics.
- Mandatory elective for a major in Physics and ECE
- The curriculum is tightly integrated with the curriculum of the modules "Calculus and Elements of Linear Algebra I and II" .
- It is also valuable for students in Computer Science, IMS, either as part of a minor in Mathematics, or as an elective module.
- This module is an elective for students of all other undergraduate studies.

Examination Type: Module Component Examinations

Module Component 1: Lecture

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

Scope: Intended learning outcomes of the lecture (5, 7).

Module Component 2: Lecture

Assessment Type: Lab report — Length: Approx. 30 pages, Weight: 33%

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

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

7.4 Number Theory

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

Number Theory</td><td>Module Code
CO-500</td><td>Level (type)

Year 2/3 (CORE)</td><td>CP

5.0</td></tr>
<tr><td colspan="6">Module Components</td></tr>
<tr><td colspan="3">Number</td><td>Name</td><td>Type</td><td>CP</td></tr>
<tr><td colspan="3">CO-500-A</td><td>Number Theory</td><td>Lecture</td><td>5.0</td></tr>
<tr><td colspan="3">Module Coordinator

K. Mallahi-Karai</td><td>Program Affiliation

• Mathematics</td><td colspan="2">Mandatory Status

Mandatory elective for Mathematics</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 “Applied Calculus” and “Finite Mathematics”</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

It is recommended to have taken the Methods module: Calculus and Elements of Linear Algebra I and II
Some basic familiarity with linear algebra is useful, but not technically required.</td></tr>
<tr><td colspan="6">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.</td></tr>
<tr><td colspan="6">Intended Learning Outcomes
By the end of the module, students will be able to

• demonstrate their mastery of basic tools of number theory;
• develop the ability to use number theoretic concepts and structures for applications in cryptographic platforms;</td></tr>
</table>

- analyze the definitions of basic number theoretical concepts such as primes numbers, congruences, and finite fields;
- 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. Koblit (1994). A course in Number Theory and Cryptography, second edition. Berlin: Springer.

Usability and Relationship to other Modules

- This module can be taken as a specialization / CORE module in Mathematics in Semester 3 or 5.
- 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, IMS, and ECE.

Examination Type: Module Examination

Assessment Type: Written examination

Duration: 120 min
Weight: 100%

Scope: All intended learning outcomes of this module

7.5 Discrete Mathematics

Module Name			*Module Code*	*Level (type)*	*CP*
Discrete Mathematics			CO-501	Year 2/3 (CORE)	*5.0*
Module Components					
Number	*Name*			*Type*	*CP*
CO-501-A	Discrete Mathematics			Lecture	5.0
Module Coordinator K. Mallahi-Karai	*Program Affiliation* • Mathematics			*Mandatory Status* Mandatory elective for Mathematics, CS, Physics and IMS	
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 “Applied Calculus” and “Finite Mathematics”	*Frequency* Annually (Spring) *Duration* 1 semester	*Forms of Learning and Teaching* • Lectures (35 hours) • Private Study (90 hours) *Workload* 125 hours	

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

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 lecutre 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.

Intended Learning Outcomes

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

- demonstrate their mastery of basic tools in discrete mathematics.
- develop the ability to use discrete mathematics concepts (such as graphs) to model problems in computer science.
- analyze the definition of basic combinatorial objects such as graphs, permutations, partitions, etc.
- formulate and design methods sand algorithms for solving applied problems basic 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 a specialization / CORE module in Mathematics to be taken in Semester 4 or 6.
- This module is recommended for students pursuing a minor in Mathematics
- This module serves as a mandatory elective Methods and Skills module for CS, Physics and IMS
- This module is a good option as an elective module for students in IMS.

Examination Type: Module Examination

Assessment Type: Written examination

Duration: 120 min
Weight: 100%

Scope: All intended learning outcomes of this module

7.6 Undergraduate Seminar

Module Name		*Module Code*	*Level (type)*	*CP*
Undergraduate Seminar		CO-502	Year 2 (CORE)	5
Module Components				
Number	*Name*		*Type*	*CP*
CO-502-A	Undergraduate Seminar Part I		Seminar	2.5
CO-502-B	Undergraduate Seminar Part II		Seminar	2.5
Module Coordinator I. Gorbovickies	*Program Affiliation* • Mathematics		*Mandatory Status* Mandatory for Mathematics	
Entry Requirements *Pre-requisites* ☒ Linear Algebra ☒ Analysis I	*Co-requisites* ☒ None	*Knowledge, Abilities, or Skills* • None beyond formal prerequisites	*Frequency* Annually (Fall/Spring)	*Forms of Learning and Teaching* • Seminar (35 hours) • Private study (90 hours)
			Duration 2 semesters	*Workload* 125 hours

Recommendations for Preparation

Contact Instructor of Record ahead of time for a summer/winter intersession reading list.

Content and Educational Aims

The Undergraduate Seminar is a module in which students give presentations on a particular area of mathematics, jointly discuss the topic of the presentation, and also discuss and reflect on presentation styles and the role of the subject topic in a broader context. The topics for the presentations are chosen by the instructor in consultation with the class and may come from a wide range of mathematical areas, typically outside of the standard first or second year math curriculum.

The goals of the module are threefold. First, it develops skills in mathematical communication: presentation, discussion, writing, and working with mathematical literature. Second, it provides a perspective on selected advanced and/or current topics in mathematics. Third, it helps students identify interesting areas of research and possible thesis subjects and advisors, as some of the suggested topics will relate to the research interests of the mathematics faculty.

Intended Learning Outcomes

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

- read and understand basic research literature in some areas of mathematics;
- employ effective strategies for self-learning in a well-defined but new subfield of mathematics;
- use common strategies, tools, and data bases for literature searches;
- know the advantages and disadvantages of blackbox vs. slide-based presentations and the software tools for mathematical slides;
- communicate mathematical results in a comprehensive way in at least one chosen style of presentation;
- think critically about their own and other students' presentations;
- respond to feedback in a constructive way.

Indicative Literature

Not specified- changing topics

Usability and Relationship to other Modules

- This module is part of the core education in Mathematics
- Mandatory for a Major in Mathematics
- Mandatory for a Minor in Mathematics
- This module is an elective for students of all other undergraduate studies
- It is also valuable for students in Physics, Computer Science, IMS, 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 "Calculus and Elements of Linear Algebra I and II" in the following way: "Calculus and Elements of Linear Algebra 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: Presentation

Duration: 45 min (each part)
Weight: 100%

Scope: All intended learning outcomes of this module

7.7 Introductory Algebra

Module Name	*Module Code*	*Level (type)*	*CP*
Introductory Algebra	CO-503	Year 2 (CORE)	*7.5*

Module Components

Number	*Name*	*Type*	*CP*
CO-503-A	Introductory Algebra	Lecture	5
CO-503-B	Introductory Algebra Tutorial	Tutorial	2.5

Module Coordinator	*Program Affiliation*	*Mandatory Status*
I. Penkov	• Mathematics	Mandatory for Mathematics

Entry Requirements			*Frequency*	*Forms of Learning and Teaching*
Pre-requisites	*Co-requisites*	*Knowledge, Abilities, or Skills*	Annually (Fall)	• Lectures (35 hours) • Tutorials (17.5 hours) • Private study (135 hours)
☒ *Linear Algebra*	☒None	• None beyond formal pre-requisites	*Duration* 1 semester	*Workload* 187.5 hours

Recommendations for Preparation

Review material from Linear Algebra

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.

Intended Learning Outcomes By the end of the module, students will be able to • demonstrate their mastery of basic methods and concepts from Algebra to independently solve problems in that field; • assess the central importance of group theory and its applications to different areas of math; • explain the definitions of groups, rings, ideals, fields, and modules; • compare different examples of groups, rings, ideals, fields and modules from mathematics and physics.
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 • This module is a mandatory module for Mathematics • 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

7.8 Analysis III

Module Name			Module Code	Level (type)	CP
Analysis III			CO-504	Year 2 (CORE)	7.5
Module Components					
Number	Name			Type	CP
CO-504-A	Analysis III			Lecture	5
CO-504-B	Analysis III Tutorial			Tutorial	2.5
Module Coordinator S. Petrat	Program Affiliation • Mathematics			Mandatory Status Mandatory for Mathematics	
Entry Requirements Pre-requisites: ☒ Analysis I ☒Applied Mathematics	Co-requisites ☒ None	Knowledge, Abilities, or Skills • None beyond formal pre-requisites	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 Review material from Analysis I and Applied Mathematics					

Content and Educational Aims

This module is the third module in the core Analysis education for students in Mathematics. It builds on the two independent modules "Analysis I" and "Applied Mathematics" and provides a more abstract point of view. In the first part of the module, the Riemann integral is generalized to the Lebesgue notion of integration which 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 a brief introduction to measure theory without aiming for a comprehensive treatment to arrive early at the notion of 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.

In the second part of the module the notions of gradient, curl and divergence will be discussed in terms of operations on vector fields and differential forms on manifolds, examples of which will be given in various areas of mathematics. The theory of the integration of differential forms will be provided and the Stokes' Theorem, which is already known from the special settings in the "Applied Mathematics" module, will be proved. Finally, basic concepts of differential geometry (connection, parallel transport, and curvature) will be introduced.

Intended Learning Outcomes
By the end of the module, students will be able to

- distinguish between the Riemann and Lebesgue integrals;
- use the central limit theorems in a variety of contexts;
- formulate and employ the central properties of Lebesgue spaces;
- explain the definition of a manifold and its tangent space;
- transform notions from elementary vector analysis into an intrinsic geometric setting.

Indicative Literature

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

J. Lee (2013). Introduction to Smooth Manifolds, 2nd edition. Berlin: Springer.

M. Spivak, (1965). Calculus on Manifolds. Boston: Addison-Wesley.

Usability and Relationship to other Modules

- This module is a mandatory module for Mathematics
- Elective for students in Physics and possibly other majors
- 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 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

7.9 Real Analysis

Module Name			*Module Code*	*Level (type)*	*CP*
Real Analysis			CA-S-MATH-801	Year 2/3 (Specialization)	5
Module Components					
Number	*Name*			*Type*	
CA-MATH-801	Real Analysis			Lecture	
Module Coordinator	*Program Affiliation*			*Mandatory Status*	
M. Oliver	• Mathematics			Mandatory elective for Mathematics	
Entry Requirements			*Frequency*	*Forms of Learning and Teaching*	
Pre-requisites	*Co-requisites*	*Knowledge, Abilities, or Skills*	Biennially (Spring)	• Lectures (35 hours) • Private study (90 hours)	
☒Analysis I ☒Applied Mathematics ☒Linear Algebra	☒ None	• None beyond formal pre-requisites	*Duration* 1 semester	*Workload* 125 hours	

Recommendations for Preparation

Review material from pre-requisite modules. Knowledge of some topics from Analysis III is helpful but not required.

Content and Educational Aims

This module focuses on the description, analysis, and representation of linear functionals and operators defined on general topological vector spaces, most prominently on abstract Banach and Hilbert spaces. Even though abstract in nature, the tools of Real Analysis play a central role in applied mathematics, e.g., in partial differential equations. To illustrate this strength of Real Analysis is one of the goals of this module.

Topics covered in this module include: point-set topology (at a deeper level than in Analysis I), Banach spaces, the Hahn-Banach theorem, weak topologies, compactness theorems (Tychnov's theorem, Banach-Alaoglu theorem, and the Arzela-Ascoli theorem), Hilbert spaces, and the Lebesgue spaces, spectral theory of compact operators.

Intended Learning Outcomes

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

- demonstrate their mastering of advanced methods and concepts from Real Analysis to independently solve mathematical problems in that field;
- summarize the theory of operators on Banach and Hilbert spaces;
- analyze continuity, boundedness and compactness in the broader context of linear operators;
- apply the tools of Real Analysis in other branches of mathematics.

Indicative Literature

G.B. Folland, (1999). Real Analysis - Modern Techniques and their Applications, second edition. New York: Wiley.

E.H. Lieb, M. Loss (2001). Analysis. Rhode Island: AMS, 2001

Usability and Relationship to other Modules

- This module is a specialization module in Mathematics to be taken in Semester 3 or 5.

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

7.10 Complex Analysis

Module Name		*Module Code*	*Level (type)*	*CP*
Complex Analysis		CA-S-MATH-802	Year 2/3 (Specialization)	*5.0*
Module Components				
Number	*Name*		*Type*	*CP*
CA-MATH-802	Complex Analysis		Lecture	5.0
Module Coordinator A. Huckleberry	*Program Affiliation* • Mathematics		*Mandatory Status* Mandatory elective for Mathematics	
Entry Requirements *Pre-requisites*: ☒Analysis I or Calculus and Elements of Linear Algebra II *Co-requisites*: ☒ None *Knowledge, Abilities, or Skills*: • None beyond formal pre-requisites		*Frequency* Biennially (Fall)	*Forms of Learning and Teaching* • Lectures (35 hours) • Private study (90 hours)	
		Duration 1 semester	*Workload* 125 hours	

Recommendations for Preparation

Review material from pre-requisite modules

Content and Educational Aims

Complex analysis begins with the study of holomorphic functions on domains in the complex plane. Various equivalent definitions for holomorphy are proved, the simplest being that locally such a function has a convergent power series development in the standard coordinate of the complex numbers. The Local holomorphic change of coordinates reduces the local theory to the study of complex monomials and as a consequence it is proved that non-constant holomorphic functions are open maps, have discrete level sets and do not take on their local maxima.

The global theory starts with the Cauchy Integral Theorem and the resulting Integral Formula which describes holomorphic functions as boundary integrals. This also provides methods of construction for holomorphic functions and their physically relevant harmonic real parts. Other methods of construction utilize a subtle approximation theory, in the topology of uniform convergence on compact subsets, which is intertwined with the homotopy characteristics of the domain at hand. Simply connected domains that do not coincide with the plane itself are shown to be equivalent to the unit disk (Riemann's mapping theorem). An indication of the general version of this result (the Uniformization Theorem) is sketched. In the study of more general one-dimensional complex manifolds (Riemann surfaces) which is initiated in the module, the interaction of analysis, geometry and symmetry considerations becomes more transparent.

Intended Learning Outcomes

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

- give precise proofs of the basic results of the subject;
- use the theory to compute quantities, e.g., integrals, of importance;
- have intuition for the interaction of the analytic and geometric sides of the subject;
- be in a position of initiating a study of the higher-dimensional theory.

Indicative Literature

R. Narasimhan (1985). Complex Analysis in 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 specialization module in Mathematics to be taken in Semester 3 or 5.

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

7.11 Stochastic Processes

Module Name				*Module Code*	*Level (type)*	*CP*
Stochastic Processes				CA-S-MATH-803	Year 2/3 (Specialization)	*5.0*
Module Components						
Number	*Name*				*Type*	*CP*
CA-MATH-803	Stochastic Processes				Lecture	5.0
Module Coordinator	*Program Affiliation*				*Mandatory Status*	
K. Mallahi-Karai	• Mathematics				Mandatory elective for Mathematics and IMS	
Entry Requirements				*Frequency*	*Forms of Learning and Teaching*	
Pre-requisites	*Co-requisites*	*Knowledge, Abilities, or Skills*		Biennially (Fall)	• Lectures (35 hours) • Private study (90 hours)	
☒ "Applied Mathematics" or "Probability and Random Processes"	☒None	• None beyond formal pre-requisites		*Duration*	*Workload*	
				1 semester	125 hours	
Recommendations for Preparation						
Review of Probability and Analysis I						

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.

Intended Learning Outcomes By the end of the module, students will be able to • demonstrate their mastery of basic stochastic methods; • develop ability to use stochastic processes to model real-world problems, e.g. in finance; • analyze the definition of basic probabilistic objects, and their numerical features; • formulate and design methods and algorithms for solving applied problems based on ideas from stochastic processes.
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 • This module is a specialization module in Mathematics to be taken in Semester 4 or 6. • Serves as a mandatory elective 3rd year Specialization module for IMS major students.
Examination Type: Module Examination Assessment Type: Written examination — Duration: 120 min, Weight: 100% Scope: All intended learning outcomes of this module

7.12 Numerical Analysis

<table>
<tr><td colspan="3">Module Name
Numerical Analysis</td><td>Module Code
CA-S-MATH-804</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- MATH-804</td><td colspan="3">Numerical Analysis</td><td>Lecture</td><td>5</td></tr>
<tr><td>Module Coordinator

T. Preusser</td><td colspan="3">Program Affiliation

• Mathematics</td><td colspan="2">Mandatory Status

Mandatory elective for Mathematics</td></tr>
<tr><td colspan="3">Entry Requirements</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>Pre-requisites

☒Analysis I or Applied Mathematics
☒Linear Algebra I</td><td>Co-requisites

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

The following modules are recommended, but not required prior to taking this module: Numerical methods
•
• Applied Mathematics</td><td>Duration

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

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

• Revise your knowledge in Analysis and Linear Algebra</td></tr>
<tr><td colspan="6">Content and Educational Aims
The module is an introduction to the analysis of basic classes of numerical algorithms used in large-scale scientific computing. It introduces the fundamental notions and concepts of numerical mathematics. Then, successively, iterative solvers, interpolation, and quadrature are discussed and analyzed. They serve as the core numerical building blocks for an introduction to the finite element method (FEM) as one of the modern numerical techniques widely used in engineering applications and theoretical physics.

The following topics will be covered:
• Principles of Numerical Mathematics: well-posedness, stability, robustness, condition, and consistency
• Equivalence theorem of Lax-Richtmeyer for exemplary problems
• Types of error analysis (forward, backward, a priori, and a posteriori)
• Sources of errors (modeling, data, discretization, rounding, and truncation)
• Foundations of matrix analysis: Vector norms and matrix norms and compatible/consistent norms
• Stability analysis for linear systems: the condition number of a matrix, forward/backward a priori analysis, and the convergence of iterative methods
• Iterative methods: gradient descent and conjugate gradient method
• Review of Lagrange interpolation, error estimates, drawbacks, Runge’s counterexample, the stability of polynomial interpolation, piecewise Lagrange interpolation, and extensions to the multi-dimensional case
• Quadrature formulas: interpolatory quadrature, error estimates, Gauss quadrature, degree of exactness, and extensions to the multi-dimensional case
• Finite difference approximations, stability and convergence analysis for FDM, and error estimates for FDM</td></tr>
</table>

- The notion of a weak solution
- The Ritz-Galerkin method and the Finite Element Method (FEM)
- Error estimates for FEM: Cea's Lemma, and approximation estimates
- Particular examples in 1D and 2D and linear and quadratic shape functions

Intended Learning Outcomes

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

- demonstrate their mastering of advanced methods and concepts
- explain fundamental notions of numerical mathematics: well-posedness, stability, robustness, condition, consistency, convergence
- independently approach mathematical problems using discretization and numerical methods
- assess the central importance of numerical analysis for applied mathematics, and applications, e.g., from physics or engineering
- summarize the theory behind advanced numerical methods like the finite element method

Indicative Literature

A. Quarteroni, R. Sacco, F. Saleri (2007). Numerical Mathematics, second edition. Berlin: Springer.

Usability and Relationship to other Modules

- This module addresses all students of Mathematics
- Optional for a Minor or a Major in Mathematics
- Elective for students of all other undergraduate studies
- It is of particular importance for students with an interest in Applied Mathematics or Scientific Computing
- It is also valuable for students in Physics 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

7.13 Dynamical Systems

Module Name		*Module Code*	*Level (type)*	*CP*
Dynamical Systems		CA-S-MATH-805	Year 2/3 (Specialization)	*5.0*
Module Components				
Number	*Name*		*Type*	*CP*
CA-MATH-805	Dynamical Systems		Lecture	5.0
Module Coordinator I. Gorbovickies	*Program Affiliation* • Mathematics		*Mandatory Status* Mandatory elective for Mathematics	
Entry Requirements *Pre-requisites* ☒ "Analysis I" or "Applied Mathematics"	*Co-requisites* ☒None	*Knowledge, Abilities, or Skills* • None beyond formal pre-requisites	*Frequency* (Biennially) (Spring) *Duration* 1 semester	*Forms of Learning and Teaching* • Lectures (35 hours) • Private study (90 hours) *Workload* 125 hours
Recommendations for Preparation Review material from Analysis I and Applied Mathematics				

Content and Educational Aims

This module is an introduction to dynamical systems. Dynamical systems naturally arise from iterations of maps or 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
- periodic orbits
- differential equations in the plane and the Poincarè-Bendixon theorem
- chaotic dynamics, e.g., in the Lorenz system
- asymptotic techniques
- structural stability
- bifurcation theory

Intended Learning Outcomes By the end of the module, students will be able to • demonstrate their mastery of advanced methods and concepts from Dynamical Systems to independently solve mathematical problems in that field; • assess the central importance of the theory of dynamical systems in analyzing the long-term behavior of continuous processes; • compare the qualitative behaviors of various dynamical systems; • 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 • This module is a specialization module in Mathematics to be taken in Semester 4 or 6.
Examination Type: Module Examination Assessment Type: Written examination — Duration: 120 min; Weight: 100% Scope: All intended learning outcomes of this module

7.14 Foundations of Mathematical Physics

Module Name			*Module Code*	*Level (type)*	*CP*
Foundations of Mathematical Physics			CA-S-MATH-806	Year 2/3 (Specialization)	*5*
Module Components					
Number	*Name*			*Type*	*CP*
CA- MATH-806	Foundations of Mathematical Physics			Lecture	5
Module Coordinator S. Petrat	*Program Affiliation* • Mathematics			*Mandatory Status* Mandatory elective for Mathematics and Physics	
Entry Requirements *Pre-requisites* ☒ Applied Mathematics Or ☒Introduction to Robotics and Intelligent Systems (IMS)	*Co-requisites* ☒None	*Knowledge, Abilities, or Skills* • Good command of linear algebra, analysis, and calculus	*Frequency* Biennially (Spring) *Duration* 1 semester	*Forms of Learning and Teaching* • Lectures (35 hours) • Private study (90 hours) *Workload* 125 hours	
Recommendations for Preparation Review material from pre-requisite modules, especially Applied Mathematics. Having taken Applied Mathematics is recommended.					

Content and Educational Aims

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

A selection of the following topics will be covered:

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

Intended Learning Outcomes
By the end of the module, students will be able to

- demonstrate the application of mathematics in the context of physics
- explain the mathematical foundations of classical mechanics, quantum mechanics, statistical physics, and electrodynamics
- discuss the solutions to both linear and non-linear equations in physics
- breakdown the Hamiltonian formalism in the context of classical and quantum mechanics
- 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

- This module is a mandatory elective module in Mathematics to be taken in Semester 3 or 5.
- Possible mandatory Elective for a minor in Mathematics
- Mandatory elective for a major in Mathematics
- Mandatory elective Specialization module for a major Physics
- Elective for students of all other undergraduate studies

Examination Type: Module Examination

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

7.15 Partial Differential Equations

Module Name	*Module Code*	*Level (type)*	*CP*
Partial Differential Equations	CA-S-MATH-807	Year 2/3 (Specialization)	*5*

Module Components

Number	*Name*	*Type*	*CP*
CA-MATH-807	Partial Differential Equations	Lecture	5

Module Coordinator	*Program Affiliation*	*Mandatory Status*
M. Oliver	• Mathematics	• Mandatory elective for Mathematics

Entry Requirements			*Frequency*	*Forms of Learning and Teaching*
Pre-requisites	*Co-requisites*	*Knowledge, Abilities, or Skills*	Biennially (Spring)	• Lectures (35 hours) • Private study (90 hours)
☒Analysis I or Applied Mathematics	☒None	It is strongly recommended that students take the module "Applied Mathematics" before taking this module	*Duration* 1 semester	*Workload* 125 hours

Recommendations for Preparation

- Revise your knowledge in Analysis

Content and Educational Aims

The module is an introduction to the theory of partial differential equations. The main topics are: classification of PDEs, and linear prototypes (transport equation, Poisson equation, heat equation, and wave equation); classical theory for linear elliptic second order equations; functional setting, function spaces, variational methods, weak derivatives and weak solutions; examples of nonlinear parabolic PDEs, and introduction to conservation laws; and exact solution techniques, transformation methods, power series solutions, and asymptotics. To attend the class, students should have good command of analysis, some knowledge of real analysis is beneficial.

The following topics will be covered:

- Examples of PDEs
- Classification of PDEs
- Laplace's equation and Poisson's equation
- The Dirichlet problem
- Mean value formulas
- Maximum principles and theuniqueness of solutions
- Harmonic, sub-harmonic and super-harmonic functions
- Liouville's theorem and Harnack's inequality
- Fundamental solution and Green's function
- Poisson's integral formula
- Perron's method and the method of continuity
- The regularity of classical solutions
- Weak derivatives
- Approximation by smooth functions
- Weak solutions
- Wave equation: D'Alembert's formula and energy methods
- First order PDEs: method of characteristics
- Scalar conservation laws and Hamilton-Jacobi equations

- Legendre transform and the Hopf-Lax formula

Intended Learning Outcomes

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

- demonstrate their mastery of advanced methods and concepts
- independently solve mathematical problems involving partial differential equations
- assess the central importance of partial differential equations for applied and pure mathematics, and applications, e.g., from physics or engineering
- compare different examples of partial differential equations
- analyze linear elliptic 2nd order equations with the classical solution theory
- summarize the concept behind the weak solution theory for second order elliptic equations

Indicative Literature

L.C. Evans (2010). Partial Differential Equations. Rhode Island: AMS.

Usability and Relationship to other Modules

- This module is of importance for all students of Mathematics
- Elective for a Minor in Mathematics
- Elective for a Major in Mathematics
- Elective for students of all other undergraduate studies
- It is also valuable for students in Physics 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

7.16 Algebra

<table>
<tr><td colspan="3">Module Name
Algebra</td><td>Module Code
CA-S-MATH-808</td><td>Level (type)
Year 2/3 (Specialization)</td><td>CP
5.0</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-MATH-808</td><td colspan="3">Algebra</td><td>Lecture</td><td>5.0</td></tr>
<tr><td>Module Coordinator
I. Penkov</td><td colspan="3">Program Affiliation
• Mathematics</td><td colspan="2">Mandatory Status
Mandatory elective for Mathematics</td></tr>
<tr><td colspan="3" rowspan="2">Entry Requirements
Pre-requisites: ☒Introductory Algebra
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 material from Introductory Algebra</td></tr>
<tr><td colspan="6">Content and Educational Aims
This module is about advanced topics from Algebra, including groups, rings, ideals, fields, and modules, continuing the module Introductory Algebra. Optional topics include Fields and Galois theory.</td></tr>
<tr><td colspan="6">Intended Learning Outcomes
By the end of the module, students will be able to
• demonstrate their mastery of advanced methods and concepts from Algebra to independently solve mathematical problems in that field;
• assess the central importance of group theory and its role in mathematics and physics;
• explain the definitions of groups, rings, ideals, fields and modules;
• compare different examples of groups, rings, ideals, fields and modules from mathematics and physics.</td></tr>
<tr><td colspan="6">Indicative Literature
T.W. Hungerford (2003). Algebra, eighth edition. Berlin: Springer.
S. Lang (2005) Algebra, third edition. Berlin: Springer.
J. Rotman (2005). A First Course in Abstract Algebra, third edition. New York: Pearson.</td></tr>
<tr><td colspan="6">Usability and Relationship to other Modules
• This module is a specialization module in Mathematics to be taken in Semester 4 or 6.</td></tr>
<tr><td colspan="4">Examination Type: Module Examination
Assessment Type: Written examination

Scope: All intended learning outcomes of this module</td><td colspan="2">Duration: 120 min
Weight: 100%</td></tr>
</table>

7.17 Topology

Module Name	*Module Code*	*Level (type)*	*CP*
Topology	CA-S-MATH-809	Year 2/3 (Specialization)	*5*

Module Components

Number	*Name*	*Type*	*CP*
CA-MATH-809	Topology	Lecture	5

Module Coordinator	*Program Affiliation*	*Mandatory Status*
A. Huckleberry	• Mathematics	Mandatory elective for Mathematics

Entry Requirements

Pre-requisites	*Co-requisites*	*Knowledge, Abilities, or Skills*	*Frequency*	*Forms of Learning and Teaching*
☒ Calculus and Elements of Linear Algebra I and II ☒ Advanced Calculus	☒ None	• Good command of linear algebra, analysis, and calculus	Biennially (Spring)	• Lectures (35 hours) • Private study (90 hours)

Duration	*Workload*
1 semester	125 hours

Recommendations for Preparation

Review material from pre-requisite modules.

Content and Educational Aims

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

The second half of the module is devoted to elementary homotopy theory and its connection to homology. After an introduction to the basic definitions, first results, e.g. homotopy lifting, are proved. The universal cover is constructed and the accompanying free proper action of the fundamental group, along with intermediate covering spaces, are discussed. Surfaces provide a large class of interesting examples. Finally, the first ideas on homology are introduced and its connection to homotopy (Hurewicz Theorems) is sketched.

Intended Learning Outcomes

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

- give precise proofs of basic set-theoretical topological results in the appropriate level of abstraction;
- make a catalogue of examples and counterexamples for the basic concepts in set-theoretical topology;
- use homotopy theory to prove topological classification theorems, e.g., for surfaces;
- provide hands-on examples of homotopy groups and covering theory;
- initiate the study of more advanced topics in algebraic topology.

Indicative Literature

A. Hatcher, Algebraic (2002). Topology. Cambridge: Cambridge University Press.

G.E. Bredon (1993). Topology and Geometry. Berlin: Springer.

Usability and Relationship to other Modules

- This module is an Elective module in Mathematics to be taken in Semester 3 or 5.
- Elective for a Minor in Mathematics
- Elective for a Major in Mathematics

• Elective for students of all other undergraduate studies
Examination Type: Module Examination Assessment Type: Written examination — Duration: 120 min, Weight: 100% Scope: All intended learning outcomes of this module

7.18 Applied Dynamical Systems Lab

Module Name Applied Dynamical Systems Lab		*Module Code* CA-S-MATH-810	*Level (type)* Year 2/3 (Specialization)	*CP* *7.5*
Module Components				
Number	*Name*		*Type*	*CP*
CA-MATH-810	Applied Dynamical Systems Lab		Lecture with integrated Lab component	7.5
Module Coordinator M. Oliver	*Program Affiliation* • Mathematics		*Mandatory Status* Mandatory elective for Mathematics	
Entry Requirements *Pre-requisites* ☒ Calculus and Elements of Linear Algebra II	*Co-requisites* ☒ None	*Knowledge, Abilities, or Skills* • Python programming as can be learned in the first-year module "Applied Mathematics" or any Programming in Python classica • Advanced Multivariable Calculus as taught in the first-year module "Applied Mathematics" is helpful, but not required. • Analysis I is helpful, but not required.	*Frequency* Biennially (Fall) *Duration* 1 semester	*Forms of Learning and Teaching* • Class Sessions (51.5 hours) • Private study (135 hours) *Workload* 187.5 hours
Recommendations for Preparation • Review the content of Calculus and Elements of Linear Algebra 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 Phython*).				
Content and Educational Aims This module is a hands-on introduction to the theory and applications of dynamical systems. A crucial component of this class is the use of computer experiments to foster intuitive understanding and develop students' skills in using the computer to bridge the gap between mathematical idea and concrete implementation and application. The module is taught as an integrated lecture-lab, where short theoretical units are interspersed with interactive computation and computer experiments. Topics include nonlinear oscillators, coupled pendula, and pattern formation in chemical reactions. A main focus of the lab is the development of standard tools for the numerical solution of differential equations, the application of automated tools for bifurcation analysis, and continuation methods. We will also implement simple agent-based models and pseudo-spectral PDE solvers for reaction-diffusion equations.				

Intended Learning Outcomes
By the end of the module, students will be able to

- apply and reason about fundamental concepts of deterministic and stochastic modeling;
- implement standard mathematical algorihms in *Python/Numpy* and/or *Mathematica;*
- design, conduct, and interpret controlled in-silico scientific experiments;
- demonstrate the mastering of numerical methods to solve differential equations;
- use a version control system for collaboration and the submission of code and reports.

Indicative Literature

J. Sethna (2006). Statistical Mechanics: Entropy, Order Parameters, and Complexity. Oxford: Oxford University Press.

S. Strogatz (2014). Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry, and Engineering, second edition. Boulder: Westview Press.

Usability and Relationship to other Modules

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

Examination Type: Module Examination

Assessment Type: Project (portfolio)

Weight: 100%

Scope: All intended learning outcomes of this module

7.19 Stochastic Methods Lab

<table>
<tr><td colspan="3">Module Name
Stochastic Methods Lab</td><td>Module Code
CA-S-MATH-811</td><td>Level (type)
Year 2/3 (Specialization)</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>CA-MATH-811</td><td colspan="3">Stochastic Methods Lab</td><td>Lecture with integrated Lab component</td><td>7.5</td></tr>
<tr><td>Module Coordinator

S. Petrat</td><td colspan="3">Program Affiliation

• Mathematics</td><td colspan="2">Mandatory Status

Mandatory elective for Mathematics and IMS</td></tr>
<tr><td rowspan="2">Entry Requirements

Pre-requisites

☒Calculus and Elements of Linear Algebra I and II</td><td rowspan="2">

Co-requisites

☒ None</td><td rowspan="2">

Knowledge, Abilities, or Skills

• Python programming as can be learned in the first-year module “Applied Mathematics” or any Programming in Python class
• Advanced Multivariable Calculus as taught in the first-year module “Applied Mathematics” is helpful, but not required.
• Analysis I is helpful, but not required.
•</td><td>Frequency

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

• Class sessions (52.5 hours)
• Private study (135 hours)</td></tr>
<tr><td>Duration

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

187.5 hours</td></tr>
<tr><td colspan="6">Recommendations for Preparation
• Review the content of Calculus and Elements of Linear Algebra 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. Students will program and explore all basic techniques in a numerical programming environment and apply these algorithms to real data whenever possible.</td></tr>
</table>

Intended Learning Outcomes
By the end of the module, students will be able to

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

Indicative Literature

Y.-D. Lyuu (2002). Financial Engineering and Computation - Principles, Mathematics, Algorithms. Camridge: 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 Applied Mathematics
- It is also valuable for students in Physics, Computer Science, IMS, and ECE, either as part of a minor in Mathematics, or as an elective module.
- Serves as a mandatory elective 3rd year specialization module for IMS major students.

Examination Type: Module Examination

Assessment Type: Project (portfolio)

Weight: 100%

Scope: All intended learning outcomes of this module

7.20 Algebraic Topology

<table>
<tr><td colspan="3">Module Name
Algebraic Topology</td><td>Module Code
CA-S-MATH-812</td><td>Level (type)
Year 2/3 (Specialization)</td><td>CP
5.0</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-MATH-812</td><td colspan="3">Algebraic Topology</td><td>Lecture</td><td>5.0</td></tr>
<tr><td>Module Coordinator
I. Penkov</td><td colspan="3">Program Affiliation
• Mathematics</td><td colspan="2">Mandatory Status
Elective for Mathematics</td></tr>
<tr><td colspan="3" rowspan="2">Entry Requirements
Pre-requisites: ☒ Introductory Algebra
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 material from Introductory Algebra</td></tr>
<tr><td colspan="6">Content and Educational Aims
This module is mostly concerned with the comprehensive treatment of the fundamental ideas of singular homology/cohomology theory and duality.

The first part studies the definition of homology and the properties that lead to the axiomatic characterization of homology theory. Further algebraic concepts such as cohomology and the multiplicative structure in cohomology are then introduced. In the last section the duality between the homology and cohomology of manifolds is studied and a few basic elements of obstruction theory are discussed.

The module provides a solid introduction to fundamental ideas and results that are used today in most areas of pure mathematics and theoretical physics.</td></tr>
<tr><td colspan="6">Intended Learning Outcomes
By the end of the module, students will be able to
• demonstrate their mastery of advanced methods and concepts from Algebraic Topology to independently solve mathematical problems in that field;
• assess the central importance of homology theory and its role in mathematics;
• compare different examples of homologies and cohomologies;
• analyze different calculational tools to compute homologies.</td></tr>
<tr><td colspan="6">Indicative Literature
G.E. Bredon (1997). Topology and Geometry, corrected edition. Berlin: Springer.

A. Hatcher (2001). Algebraic Topology. Cambridge: Cambridge University Press.

W. Fulton (1997). Algebraic Topology: A First Course. Berlin: Springer.</td></tr>
<tr><td colspan="6">Usability and Relationship to other Modules
• This module is a specialization module in Mathematics to be taken in Semester 4 or 6.</td></tr>
</table>

Examination Type: Module Examination

Assessment Type: Written Exam — Duration: 120 min — Weight: 100%

Scope: All intended learning outcomes of this module

7.21 Internship / Startup and Career Skills

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

Predrag Tapavicki & Christin Klähn (CSC Organization); SPC / Faculty Startup Coordinator (Academic responsibility);</td><td colspan="3">Program Affiliation

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

Mandatory for all undergraduate study programs except IEM</td></tr>
<tr><td rowspan="2">Entry Requirements

Pre-requisites

☒ at least 15 CP from CORE modules in the major</td><td rowspan="2">Co-requisites

☒ None</td><td rowspan="2">Knowledge, Abilities, or Skills

• Information provided on CSC pages (see below)
• Major specific knowledge and skills</td><td>Frequency

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

• Internship/Start-up
• Internship event
• Seminars, info-sessions, workshops and career events
• Self-study, readings, online tutorials</td></tr>
<tr><td>Duration
1 semester</td><td colspan="2">Workload

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

• Reading the information in the menu sections titled “Internship Information,” “Career Events,” “Create Your Application,” and “Seminars & Workshops” at the Career Services Center website: https://jacobs-university.jobteaser.com/en/users/sign_in?back_to_after_login=%2F
• Completing all four online tutorials about job market preparation and the application process, which can be found here: https://jacobs-university.jobteaser.com/en/users/sign_in?back_to_after_login=%2F
• Participating in the internship events of earlier classes</td></tr>
<tr><td colspan="6">Content and Educational Aims
The aims of the internship module are reflection, application, orientation, and development: for students to reflect on their interests, knowledge, skills, their role in society, the relevance of their major subject to society, to apply these skills and this knowledge in real life whilst getting practical experience, to find a professional orientation, and to develop their personality and in their career. This module supports the programs’ aims of preparing students for gainful, qualified employment and the development of their personality.

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

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 Career Services 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 Career Services Center.
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 Career Services Center (e.g. the annual Jacobs 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

- describe the scope and the functions of the employment market and personal career development;
- 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.;
- 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, work space, etc.);
- 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;
- justify professional decisions based on theoretical knowledge and academic methods;
- reflect on their professional conduct in the context of the expectations of and consequences for employers and their society;
- reflect on and set their own targets for the further development of their knowledge, skills, interests, and values;
- 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;
- discuss observations and reflections in a professional network.

Indicative Literature

Not specified

Usability and Relationship to other Modules

- Mandatory for a major in BCCB, CBT, CS, EES, GEM, IBA, IRPH, Psychology, Math, MCCB, Physics, IMS, and ISS.
- This module applies skills and knowledge acquired in previous modules to a professional environment and provides an opportunity to reflect on their relevance in employment and society. It may lead to thesis topics.

Examination Type: Module Examination

Assessment Type: Internship Report or Business Plan and Reflection	Length: approx. 3.500 words
Scope: All intended learning outcomes	Weight: 100%

7.22 Bachelor Thesis and Seminar

<table>
<tr><td colspan="3">Module Name
Bachelor Thesis and Seminar</td><td>Module Code
CA-MATH-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-MATH-800-T</td><td colspan="3">Thesis</td><td>Thesis</td><td>12</td></tr>
<tr><td>CA-MATH-800-S</td><td colspan="3">Thesis Seminar</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 rowspan="2">Entry Requirements
Pre-requisites
Students must be in the third year and have taken at least 30 CP from CORE modules of their major.</td><td rowspan="2">Co-requisites
☒ None</td><td rowspan="2">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>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>Duration
1 semester</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>
</table>

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 Jacobs 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 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.
Weight: 80%

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

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.

7.23 Jacobs Track Modules

7.23.1 Methods and Skills Modules

7.23.1.1 Calculus and Elements of Linear Algebra I

Module Name			*Module Code*	*Level (type)*	*CP*
Calculus and Elements of Linear Algebra I			JTMS-MAT-09	Year 1 (Methods)	*5*
Module Components					
Number	*Name*			*Type*	*CP*
JTMS-09	Calculus and Elements of Linear Algebra I			Lecture	5
Module Coordinator	*Program Affiliation*			*Mandatory Status*	
Marcel Oliver, Tobias Preußer	• Jacobs Track – Methods and Skills			Mandatory for CS, ECE, IMS, MATH and Physics Mandatory elective for EES	
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)	
☒ None	☒ None	• Knowledge of Pre-Calculus at High School level (Functions, inverse functions, sets, real numbers, polynomials, rational functions, trigonometric functions, logarithm and exponential function, parametric equations, tangent lines, graphs, elementary methods for solving systems of linear and nonlinear equations) • Knowledge of Analytic Geometry at High School level (vectors, lines, planes, reflection, rotation,	*Duration* 1 semester	*Workload* 125 hours	

	translation, dot product, cross product, normal vector, polar coordinates) • Some familiarity with elementary Calculus (limits, derivative) is helpful, but not strictly required.		

Recommendations for Preparation

Review all of higher-level High School Mathematics, in particular the topics explicitly named in "Entry Requirements – Knowledge, Ability, or Skills" above.

Content and Educational Aims

This module is the first in a sequence introducing mathematical methods at the university level in a form relevant for study and research in the quantitative natural sciences, engineering, Computer Science, and Mathematics. The emphasis in these modules is on training operational skills and recognizing mathematical structures in a problem context. Mathematical rigor is used where appropriate. However, a full axiomatic treatment of the subject is provided in the first-year modules "Analysis I" and "Linear Algebra".

The lecture comprises the following topics

- Brief review of number systems, elementary functions, and their graphs
- Brief introduction to complex numbers
- Limits for sequences and functions
- Continuity
- Derivatives
- Curve sketching and applications (isoperimetric problems, optimization, error propagation)
- Introduction to Integration and the Fundamental Theorem of Calculus
- Review of elementary analytic geometry
- Vector spaces, linear independence, bases, coordinates
- Matrices and matrix algebra
- Solving linear systems by Gauss elimination, structure of general solution
- Matrix inverse

Intended Learning Outcomes

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

- apply 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;
- recognize the mathematical structures in an unfamiliar context and translate them into a mathematical problem statement;
- 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

S.I. Grossman (2014). Calculus of one variable, 2nd edition. Cambridge: Academic Press.

S.A. Leduc (2003). Linear Algebra. Hoboken: Wiley.

K. Riley, M. Hobson, S. Bence (2006). Mathematical Methods for Physics and Engineering, third edition. Cambridge: Cambridge University Press.

Usability and Relationship to other Modules

- The module is a mandatory / mandatory elective module of the Methods and Skills area that is part of the Jacobs Track (Methods and Skills modules; Community Impact Project module; Language modules; Big Questions modules).
- The module is followed by "Calculus and Elements of Linear Algebra II". All students taking this module are expected to register for the follow-up module.

- A rigorous treatment of Calculus is provided in the module “Analysis I”. All students taking “Analysis I” are expected to either take this module or exceptionally satisfy the conditions for advanced placement as laid out in the Jacobs Academic Policies for Undergraduate Study.
- The second-semester module “Linear Algebra” will provide a complete proof-driven development of the theory of Linear Algebra. Students enrolling in “Linear Algebra” are expected to have taken this module; in particular, the module “Linear Algebra” will assume that students are proficient in the operational aspects of Gauss elimination, matrix inversion, and their elementary applications.
- This module is a prerequisite for the module “Applied Mathematics” which develops more advanced theoretical and practical mathematical tools essential for any physicist or mathematician.
- Mandatory for a major in CS, ECE, IMS, MATH and Physics
- Mandatory elective for a major in EES.
- Pre-requisite for Calculus and Elements of Linear Algebra II
- Elective for all other study programs.

Assessment

Type: Written examination — Duration: 120 min, Weight: 100%

Scope: All intended learning outcomes of this module

7.23.1.2 Calculus and Elements of Linear Algebra II

<table>
<tr><td colspan="3">Module Name
Calculus and Elements of Linear Algebra II</td><td>Module Code
JTMS-MAT-10</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>JTMS-10</td><td colspan="3">Calculus and Elements of Linear Algebra II</td><td>Lecture</td><td>5</td></tr>
<tr><td>Module Coordinator

Marcel Oliver, Tobias Preußer</td><td colspan="3">Program Affiliation

• Jacobs Track – Methods and Skills</td><td colspan="2">Mandatory Status

Mandatory for CS, ECE, MATH, Physics, IMS</td></tr>
<tr><td colspan="3">Entry Requirements</td><td>JTMS-MAT-10Frequency

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

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

☒ Calculus and Elements of Linear Algebra I</td><td>Co-requisites

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

• None beyond formal pre-requisites</td><td>Duration

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

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

Review the content of Calculus and Elements of Linear Algebra I</td></tr>
</table>

Content and Educational Aims

This module is the second in a sequence introducing mathematical methods at the university level in a form relevant for study and research in the quantitative natural sciences, engineering, Computer Science, and Mathematics. The emphasis in these modules is on training operational skills and recognizing mathematical structures in a problem context. Mathematical rigor is used where appropriate. However, a full axiomatic treatment of the subject is provided in the first-year modules "Analysis I" and "Linear Algebra".

The lecture comprises the following topics

- Directional derivatives, partial derivatives
- Linear maps
- The total derivative as a linear map
- Gradient and curl (elementary treatment only, for more advanced topics, in particular the connection to the Gauss and Stokes' integral theorems, see module "Applied Mathematics"
- Optimization in several variables, Lagrange multipliers
- Elementary ordinary differential equations
- Eigenvalues and eigenvectors
- Hermitian and skew-Hermitian matrices
- First important example of eigendecompositions: Linear constant-coefficient ordinary differential equations
- Second important example of eigendecompositions: Fourier series
- Fourier integral transform
- Matrix factorizations: Singular value decomposition with applications, LU decomposition, QR decomposition

Intended Learning Outcomes

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

- apply 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;
- recognize the mathematical structures in an unfamiliar context and translate them into a mathematical problem statement;

- 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

S.I. Grossman (2014). Calculus of one variable, 2nd edition. Cambridge: Academic Press.

S.A. Leduc (2003). Linear Algebra. Hoboken: Wiley.

K. Riley, M. Hobson, S. Bence (2006). Mathematical Methods for Physics and Engineering, third edition. Cambridge: Cambridge University Press.

Usability and Relationship to other Modules

- The module is a mandatory / mandatory elective module of the Methods and Skills area that is part of the Jacobs Track (Methods and Skills modules; Community Impact Project module; Language modules; Big Questions modules).
- 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.
- Mandatory for CS, ECE, MATH, Physics and IMS.
- Elective for all other study programs.

Assessment

Type: Written examination

Duration: 120 min
Weight: 100%

Scope: All intended learning outcomes of this module

7.23.1.3 Probability and Random Processes

Module Name			*Module Code*	*Level (type)*	*CP*
Probability and Random Processes			JTMS-MAT-12	Year 2 (Methods)	*5*
Module Components					
Number	*Name*			*Type*	*CP*
JTMS-12	Probability and random processes			Lecture	5
Module Coordinator Marcel Oliver, Tobias Preußer	*Program Affiliation* • Jacobs Track – Methods and Skills			*Mandatory Status* Mandatory for CS, ECE, MATH, Physics, IMS Mandatory elective for EES	
Entry Requirements			*Frequency* Annually (Fall)	*Forms of Learning and Teaching* • Lectures (35 hours) • Private study (90 hours)	
Pre-requisites ☒ Calculus and Elements of Linear Algebra I & II	*Co-requisites* None	*Knowledge, Abilities, or Skills* • Knowledge of calculus at the level of a first year calculus module (differentiation, integration with one and several variables, trigonometric functions, logarithms and exponential functions). • Knowledge of linear algebra at the level of a first year university module (eigenvalues and eigenvectors, diagonalization of matrices). • Some familiarity with elementary probability theory at the high school level.	*Duration* 1 semester	*Workload* 125 hours	
Recommendations for Preparation Review all of the first year calculus and linear algebra modules as indicated in "Entry Requirements – Knowledge, Ability, or Skills" above.					
Content and Educational Aims This module aims to provide a basic knowledge of probability theory and random processes suitable for students in engineering, Computer Science, and Mathematics. The module provides students with basic skills needed for formulating real-world problems dealing with randomness and probability in mathematical language, and methods for applying a toolkit to solve these problems. Mathematical rigor is used where appropriate. A more advanced treatment of the subject is deferred to the third-year module *Stochastic Processes*.					

The lecture comprises the following topics

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

Intended Learning Outcomes

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

- 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;
- recognize the probabilistic structures in an unfamiliar context and translate them into a mathematical problem statement;
- 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

- The module is a mandatory / mandatory elective module of the Methods and Skills area that is part of the Jacobs Track (Methods and Skills modules; Community Impact Project module; Language modules; Big Questions modules).
- Students taking this module are expected to be familiar with basic tools from calculus and linear algebra.
- Mandatory for a major in CS, ECE, MATH, Physics and IMS.
- Mandatory elective for a major in EES (if pre-requisites are met).
- Elective for all other study programs.

Assessment

Type: Written examination

Duration: 120 min
Weight: 100%

Scope: All intended learning outcomes of this module

7.23.1.4 Numerical Methods

Module Name			*Module Code*	*Level (type)*	*CP*
Numerical Methods			JTMS-MAT-13	Year 2 (Methods)	*5*
Module Components					
Number	*Name*			*Type*	*CP*
JTMS-13	Numerical Methods			Lecture	5
Module Coordinator	*Program Affiliation*			*Mandatory Status*	
Marcel Oliver, Tobias Preußer	• Jacobs Track – Methods and Skills			Mandatory for ECE, MATH, Physics Mandatory elective for CS and IMS	
Entry Requirements			*Frequency*	*Forms of Learning and Teaching*	
Pre-requisites	*Co-requisites*	*Knowledge, Abilities, or Skills*	Annually (Spring)	• Lectures (35 hours) • Private study (90 hours)	
☒ None	☒ None	• Knowledge of Calculus (functions, inverse functions, sets, real numbers, sequences and limits, polynomials, rational functions, trigonometric functions, logarithm and exponential function, parametric equations, tangent lines, graphs, derivatives, anti-derivatives, elementary techniques for solving equations) • Knowledge of Linear Algebra (vectors, matrices, lines, planes, n-dimensional Euclidean vector space, rotation, translation, dot product (scalar product), cross product, normal vector, eigenvalues, eigenvectors, elementary techniques for	*Duration* 1 semester	*Workload* 125 hours	

solving systems of linear equations)		

Recommendations for Preparation

Taking Calculus and Elements of Linear Algebra II before taking this module is recommended, but not required. A thorough review of Calculus and Elements of Linear Algebra, with emphasis on the topics listed as "Knowledge, Abilities, or Skills" is recommended.

Content and Educational Aims

This module covers calculus-based numerical methods, in particular root finding, interpolation, approximation, numerical differentiation, numerical integration (quadrature), and a first introduction to the numerical solution of differential equations.

The lecture comprises the following topics

- number representations
- Gaussian elimination
- LU decomposition
- Cholesky decomposition
- iterative methods
- bisection method
- Newton's method
- secant method
- polynomial interpolation
- Aitken's algorithm
- Lagrange interpolation
- Newton interpolation
- Hermite interpolation
- Bezier curves
- De Casteljau's algorithm
- piecewise interpolation
- Spline interpolation
- B-Splines
- Least-squares approximation
- polynomial regression
- difference schemes
- Richardson extrapolation
- Quadrature rules
- Monte Carlo integration
- time stepping schemes for ordinary differential equations
- Runge Kutta schemes
- finite difference method for partial differential equations

Intended Learning Outcomes

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

- describe the basic principles of discretization used in the numerical treatment of continuous problems;
- 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;
- recognize mathematical terminology used in textbooks and research papers on numerical methods in the quantitative sciences, engineering, and mathematics to the extent that they fall into the content categories covered in this module;
- implement simple numerical algorithms in a high-level programming language;
- understand the documentation of standard numerical library code and understand the potential limitations and caveats of such algorithms.

Indicative Literature

D. Kincaid and W. Cheney (1991). Numerical Analysis: Mathematics of Scientific Computing. Pacific Grove: Brooks/Cole Publishing.

W. Boehm and H. Prautzsch (1993). Numerical Methods. Natick: AK Peters.

Usability and Relationship to other Modules

- The module is a mandatory / mandatory elective module of the Methods and Skills area that is part of the Jacobs Track (Methods and Skills modules; Community Impact Project module; Language modules; Big Questions modules).
- This module is a co-recommendation for the module "Applied Dynamical Systems Lab", in which the actual implementation in a high-level programming language of the learned methods will be covered.
- Mandatory for a major in ECE, MATH, and Physics.
- Mandatory elective for a major in CS and IMS.
- Elective for all other study programs.

Assessment

Type: Written examination

Duration: 120 min
Weight: 100%

Scope: All intended learning outcomes of this module.

7.23.2 Big Questions Modules

7.23.2.1 Water: The Most Precious Substance on Earth

<table>
<tr><td colspan="3">Module Name
Big Questions: Water: The Most Precious Substance on Earth</td><td>Module Code
JTBQ-02</td><td>Level (type)
Year 3 (Jacobs Track)</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>JTBQ-02</td><td colspan="3">Water: The Most Precious Substance on Earth</td><td>Lecture/Tutorial</td><td>5</td></tr>
<tr><td>Module Coordinator

M. Bau and D. Mosbach</td><td colspan="3">Program Affiliation

• Big Questions Area: All undergraduate study programs except IEM</td><td colspan="2">Mandatory Status

• Mandatory elective for students of all undergraduate study programs, except IEM</td></tr>
<tr><td colspan="3" rowspan="2">Entry Requirements

Pre-requisites: ☒ None

Co-requisites: ☒ None

Knowledge, Abilities, or Skills
• The ability and openness to engage in interdisciplinary issues of global relevance
• Media literacy, critical thinking, and a proficient handling of data sources</td><td>Frequency

Annually (part I: Fall; part II: Spring)</td><td colspan="2">Forms of Learning and Teaching

• Lectures (17.5 hours)
• Project work (90 hours)
• Private study (17.5 hours)</td></tr>
<tr><td>Duration

2 semesters</td><td colspan="2">Workload

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

Critically following media coverage on the module’s topics in question.</td></tr>
<tr><td colspan="6">Content and Educational Aims

All “Big Questions” (BQ) modules deal with the economic, technological, societal, and environmental contexts of the global issues and challenges of the coming decades. BQ modules intend to raise awareness of those challenges and broaden students’ horizons with applied problem solving beyond the borders of their own disciplines. Knowledge and skills offered in the interdisciplinary BQ modules support students in their development to become informed and responsible citizens in a global society.
Water is the basic prerequisite for life on our planet, but it has become a scarce resource and a valuable commodity. Water is of fundamental importance to the world’s economy and global food supply, in addition to being a driving force behind geopolitical conflict. In this module, the profound impact of water on all aspects of human life will be addressed from very different perspectives: from the natural and environmental sciences and engineering, and from the social and cultural sciences.
Following topical lectures in the Fall semester, students will work on projects on the occasion of the World Water Day (March 22) in small teams comprised of students from various disciplines and with different cultural backgrounds. This teamwork will be accompanied by related tutorials.</td></tr>
<tr><td colspan="6">Intended Learning Outcomes

Students acquire transferable and key skills in this module.

By the end of this module, students will be able to</td></tr>
</table>

- use their disciplinary factual and methodological knowledge to reflect on interdisciplinary questions by comparing approaches from various disciplines;
- advance a knowledge-based opinion on the complex module topics: on the physio-chemical properties of water, its origin and history, on the importance of water as a resource, on physical and economic freshwater scarcity, on the risks of water pollution and the challenges faced by waste water treatment, on the concept of virtual water, on the bottled water industry, and on the cultural values and meanings of water;
- formulate coherent written and oral contributions (e.g., to panel discussions) on the topic;
- perform well-organized teamwork;
- present a self-designed project in a university-wide context.

Indicative Literature

Finney, John (2015). Water. A Very Short Introduction. Oxford: Oxford University Press.

Zetland, David (2011). The End of Abundance: Economic Solutions to Water Scarcity. California: Aguanomics Press.

United Nation (January 2016): Sustainable Development Goals. Retrieved from https://www.un.org/sustainabledevelopment/sustainable-development-goals

Usability and Relationship to other Modules

- This module is a mandatory elective module in the Big Questions area, which is part of the Jacobs Track (Methods and Skills modules; Community Impact Project module; Language modules; Big Questions modules).
- Students are encouraged to relate the content of their previous modules to the topics of this module and contribute their knowledge and competencies to class discussions and activities.

Assessment

Type: Written examination	Duration: 60 min Weight: 50%
Type: Team project Scope: All intended learning outcomes of the module	Weight: 50%

7.23.2.2 Ethics in Science and Technology

Module Name			*Module Code*	*Level (type)*	*CP*
Big Questions: Ethics in Science and Technology			JTBQ-03	Year 3 (Jacobs Track)	5.0
Module Components					
Number	*Name*			*Type*	*CP*
JTBQ-03	Ethics in Science and Technology			Lecture /Projects	5.0
Module Coordinator A. Lerchl	*Program Affiliation* • Big Questions Area: All undergraduate study programs, except IEM			*Mandatory Status* • Mandatory for CBT • Mandatory elective for students of all undergraduate study programs, except IEM	
Entry Requirements *Pre-requisites* ☒ None	*Co-requisites* ☒ None	*Knowledge, Abilities, or Skills* • The ability and openness to engage in interdisciplinary issues of global relevance • Media literacy, critical thinking, and a proficient handling of data sources	*Frequency* Each semester (Fall & Spring) *Duration* 1 semester	*Forms of Learning and Teaching* • Lectures (35 hours) • Project work (55 hours) • Private study (35 hours) *Workload* 125 hours	
Recommendations for Preparation Critically following media coverage of the scientific topics in question.					

Content and Educational Aims

All "Big Questions" (BQ) modules deal with the economic, technological, societal, and environmental contexts of the global issues and challenges of the coming decades. BQ modules intend to raise awareness of those challenges and broaden students' horizons with applied problem solving that extends beyond the borders of their own disciplines. Knowledge and skills offered in the interdisciplinary BQ modules support students in their development to become informed and responsible citizens in a global society.
Ethics is an often neglected, yet essential part of science and technology. Our decisions about right and wrong influence the way in which our inventions and developments change the world. A wide array of examples will be presented and discussed, e.g., the foundation of ethics, individual vs. population ethics, artificial life, stem cells, animal rights, abortion, pre-implantation diagnostics, legal and illegal drugs, the pharmaceutical industry, gene modification, clinical trials and research with test persons, weapons of mass destruction, data fabrication, and scientific fraud.

Intended Learning Outcomes

Students acquire transferable and key skills in this module.

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

- use their disciplinary factual and methodological knowledge to reflect on interdisciplinary questions by comparing approaches from various disciplines;
- summarize and explain ethical principles;
- critically look at scientific results that seem too good to be true;
- apply the ethical concepts to virtually all areas of science and technology;
- discover the responsibilities of society and of the individual for ethical standards;
- understand and judge the ethical dilemmas in many areas of the daily life;
- discuss the ethics of gene modification at the level of cells and organisms;
- reflect on and evaluate clinical trials in relation to the Helsinki Declaration;
- distinguish and evaluate the ethical guidelines for studies with test persons;
- complete a self-designed project;
- overcome general teamwork problems;
- perform well-organized project work.

Indicative Literature

Not specified.

Usability and Relationship to other Modules

- Mandatory for CBT
- This module is a mandatory elective module in the Big Questions area that is part of the Jacobs Track (Methods and Skills modules; Community Impact Project module; Language modules; Big Questions modules).
- Students are encouraged to relate the content of their previous modules to the topics of this module and contribute their knowledge and competencies to class discussions and activities.

Assessment

Type: Written examination — Duration: 60 min

Weight: 50%

Type: Team project — Weight: 50%

Scope: All intended learning outcomes of the module

7.23.2.3 Global Health – Historical context and future challenges

Module Name			*Module Code*	*Level (type)*	*CP*
Big Questions: Global Health – Historical context and future challenges			JTBQ-04	Year 3 (Jacobs Track)	5
Module Components					
Number	*Name*			*Type*	*CP*
JTBQ-04	Global Health – Historical context and future challenges			Lecture	5
Module Coordinator A. M. Lisewski	*Program Affiliation* • Big Questions Area: All undergraduate study programs, except IEM			*Mandatory Status* • Mandatory elective for students of all undergraduate study programs, except IEM	
Entry Requirements *Pre-requisites* ☒ None	*Co-requisites* ☒ None	*Knowledge, Abilities, or Skills* • The ability and openness to engage in interdisciplinary issues of global relevance • Media literacy, critical thinking, and a proficient handling of data sources	*Frequency* Annually (Spring)	*Forms of Learning and Teaching* • Lectures (35 hours) • Private study (90 hours)	
			Duration 1 semester	*Workload* 125 hours	
Recommendations for Preparation Critically following media coverage on the module's topics in question.					
Content and Educational Aims All "Big Questions" (BQ) modules deal with the economic, technological, societal, and environmental contexts of the global issues and challenges of the coming decades. BQ modules intend to raise awareness of those challenges and broaden students' horizons with applied problem solving beyond the borders of their own disciplines. Knowledge and skills offered in the interdisciplinary BQ modules support students in their development to become informed and responsible citizens in a global society. This module gives a historical, societal, technical, scientific, and medical overview of the past and future milestones and challenges of global health. Particular focus is put on future global health issues in a world that is interconnected both through mobility and communication networks. This module presents the main milestones along the path to modern health systems, including the development of public hygiene, health monitoring and disease response, and health-related breakthroughs in science, technology, and the economy. Focus is given to pediatric, maternal, and adolescent health, as these are the areas most critical to the well-being of future generations. This module also provides key concepts in global health, epidemiology, and demographics, such as the connection between a society's economic level and its population's health status, measures of health status, demographic and epidemiologic transitions, and modern issues such as the growing fragmentation (at a personal level) of disease conditions and the resulting emergence of personalized medicine. Finally, attention is also given to less publicly prominent global health issues, such as re-emerging diseases, neglected tropical diseases, and complex humanitarian crises.					

Intended Learning Outcomes

Students acquire transferable and key skills in this module.

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

- use their disciplinary factual and methodological knowledge to reflect on interdisciplinary questions by comparing approaches from various disciplines;
- explain the historical context of current global health surveillance, response systems, and institutions;
- discuss and evaluate the imminent and future challenges to public hygiene and response to disease outbreaks in the context of a global societal network.

Indicative Literature

Richard Skolnik (2015). Global Health 101 (Essential Public Health). Burlington: Jones and Bartlett Publishers, Inc.

Usability and Relationship to other Modules

- The module is a mandatory elective module in the Big Questions area, which is part of the Jacobs Track (Methods and Skills modules; Community Impact Project module; Language modules; Big Questions modules).
- Students are encouraged to relate the content of their previous modules to the topics of this module and contribute their knowledge and competencies to class discussions and activities.

Assessment

Type: Written examination	Duration: 60 min.
Scope: All intended learning outcomes of the module	Weight: 100%

7.23.2.4 Global Existential Risks

Module Name			*Module Code*	*Level (type)*	*CP*
Big Questions: Global Existential Risks			JTBQ-05	Year 3 (Jacobs Track)	2.5
Module Components					
Number	*Name*			*Type*	*CP*
JTBQ-05	Global Existential Risks			Lecture	2.5
Module Coordinator M. A. Lisewski	*Program Affiliation* • Big Questions Area: All undergraduate study programs except IEM			*Mandatory Status* • Mandatory elective for students of all undergraduate study programs except IEM	
Entry Requirements *Pre-requisites* ☒ None	*Co-requisites* ☒ None	*Knowledge, Abilities, or Skills* • The ability and openness to engage in interdisciplinary issues of global relevance • Media literacy, critical thinking, and a proficient handling of data sources	*Frequency* Annually (Spring)	*Forms of Learning and Teaching* • Lectures (17.5 hours) • Private study (45 hours)	
			Duration 1 semester	*Workload* 62.5 hours	
Recommendations for Preparation Critically following media coverage on the module's topics in question.					
Content and Educational Aims All "Big Questions" (BQ) modules deal with the economic, technological, societal, and environmental contexts of the global issues and challenges of the coming decades. BQ modules intend to raise awareness of those challenges and broaden students' horizons with applied problem solving beyond the borders of their own disciplines. Knowledge and skills offered in the interdisciplinary BQ modules support students in their development to become informed and responsible citizens in a global society. The more we develop science and technology, the more we also learn about catastrophic and, in the worst case, even existential global dangers that put the entire human civilization at risk of collapse. These doomsday scenarios therefore directly challenge humanity's journey through time as an overall continuous and sustainable process that progressively leads to a more complex but still largely stable human society. The module presents the main known varieties of existential risks, including, for example, astrophysical, planetary, biological, and technological events or critical transitions that have the capacity to severely damage or even eradicate earth-based human civilization as we know it. Furthermore, this module offers a description of the characteristic features of these risks in comparison to more conventional risks, such as natural disasters, and a classification of global existential risks based on parameters such as range, intensity, probability of occurrence, and imminence. Finally, this module reviews several hypothetical monitoring and early warning systems as well as analysis methods that could potentially be used in strategies, if not to eliminate, then at least to better understand and ideally to minimize imminent global existential risks. This interdisciplinary module will allow students to explore this topic across diverse subject fields.					
Intended Learning Outcomes Students acquire transferable and key skills in this module.					

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

- use their factual and methodological knowledge to reflect on interdisciplinary questions by comparing approaches from various disciplines;
- explain the varieties of global existential risks;
- discuss approaches to minimize these risks;
- formulate coherent written and oral contributions on this topic.

Indicative Literature

Nick Bostrom, Milan M. Cirkovic (eds.) (2011). Global Catastrophic Risk.Oxford: Oxford University Press.

Murray Shanahan (2015). The Technological Singularity. Cambridge:The MIT Press.

Martin Rees (2003) Our Final Hour. New York: Basic Books.

Usability and Relationship to other Modules

- This module is a mandatory elective module in the Big Questions area, which is part of the Jacobs Track (Methods and Skills modules; Community Impact Project module; Language modules; Big Questions modules).
- Students are encouraged to relate the content of their previous modules to the topics of this module and contribute their knowledge and competencies to class discussions and activities.

Assessment

Type: Written examination — Duration: 60 min.
Scope: All intended learning outcomes of the module — Weight: 100%

7.23.2.5 Future - From Predictions and Visions to Preparations and Actions

<table>
<tr><td colspan="3">Module Name
Big Questions: Future: From Predictions and Visions to Preparations and Actions</td><td>Module Code
JTBQ-06</td><td>Level (type)
Year 3 (Jacobs Track)</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>JTBQ-06</td><td colspan="3">Future: From Predictions and Visions to Preparations and Actions</td><td>Lecture</td><td>2.5</td></tr>
<tr><td>Module Coordinator

Joachim Vogt</td><td colspan="3">Program Affiliation

• Big Questions Area: All undergraduate study programs, except IEM</td><td colspan="2">Mandatory Status

• Mandatory elective for students of all undergraduate study programs, except IEM</td></tr>
<tr><td colspan="3" rowspan="2">Entry Requirements

<table><tr><td>Pre-requisites</td><td>Co-requisites</td><td>Knowledge, Abilities, or Skills</td></tr><tr><td>☒ None</td><td>☒ None</td><td>• The ability and openness to engage in interdisciplinary issues of global relevance
• Media literacy, critical thinking, and a proficient handling of data sources</td></tr></table></td><td>Frequency

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

• Lecture (17.5 hours)
• Private study (45 hours)</td></tr>
<tr><td>Duration

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

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

Critically following media coverage of the module's topics in question.</td></tr>
<tr><td colspan="6">Content and Educational Aims

All "Big Questions" (BQ) modules deal with the economic, technological, societal, and environmental contexts of the global issues and challenges of the coming decades. BQ modules intend to raise awareness of those challenges and broaden students' horizons with applied problem solving that extend beyond the borders of their own disciplines. Knowledge and skills offered in the interdisciplinary BQ modules support students in their development to become informed and responsible citizens in a global society.
This module addresses selected topics related to the future as a general concept in science, technology, culture, literature, ecology, and economy, and it consists of three parts. The first part (Future Continuous) discusses forecasting methodologies rooted in the idea that key past and present processes are understood and continue to operate such that future developments can be predicted. General concepts covered in this context include determinism, uncertainty, evolution, and risk. Mathematical aspects of forecasting are also discussed. The second part (Future Perfect) deals with human visions of the future as reflected in the arts and literature, ranging from ideas of utopian societies and technological optimism to dystopian visions in science fiction. The third part (Future Now) concentrates on important current developments—such as trends in technology, scientific breakthroughs, the evolution of the Earth system, and climate change—and concludes with opportunities and challenges for present and future generations.</td></tr>
</table>

Intended Learning Outcomes

Students acquire transferable and key skills in this module.

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

- use their factual and methodological knowledge to reflect on interdisciplinary questions by comparing approaches from various disciplines;
- distinguish and qualify important approaches to forecasting and prediction;
- summarize the history of utopias, dystopias, and the ideas presented in classical science fiction;
- characterize current developments in technology, ecology, society, and their implications for the future.

Indicative Literature

United Nations (2015, September) Millennium Development Goals. Retrieved from http://www.un.org/millenniumgoals.

United Nation (2016, January): Sustainable Development Goals. Retrieved from https://www.un.org/sustainabledevelopment/sustainable-development-goals

United Nations University. https://unu.edu.

US National Intelligence Council (2017). Global Trends. Retrieved from https://www.dni.gov/index.php/global-trends-home.

International Panel on Climate Change. Retrieved from https://www.ipcc.ch.

World Inequality Lab (2017, December). World Inequality Report 2018. Retrieved from https://wir2018.wid.world.

World Health Organization. Retrieved from http://www.who.int.

World Trade Organization. Retrieved from *https://www.wto.org*

Gapminder. Retrieved from https://www.gapminder.org.

World Bank. Retrieved from http://www.worldbank.org.

Usability and Relationship to other Modules

- This module is a mandatory elective module in the Big Questions area, which is part of the Jacobs Track (Methods and Skills modules; Community Impact Project module; Language modules; Big Questions modules).
- Students are encouraged to relate the content of their previous modules to the topics of this module and contribute their knowledge and competencies to class discussions and activities.

Assessment

Type: Written examination

Duration: 60 min
Weight: 100%

Scope: All intended learning outcomes of the module

7.23.2.6 Climate Change

Module Name			*Module Code*	*Level (type)*	*CP*
Big Questions: Climate Change			JTBQ-07	Year 3 (Jacobs Track)	2.5
Module Components					
Number	*Name*			*Type*	*CP*
JTBQ-07	Climate Change			Lecture	2.5
Module Coordinator L. Thomsen/ V. Unnithan	*Program Affiliation* • Big Questions Area: All undergraduate study programs, except IEM			*Mandatory Status* • Mandatory elective for students of all undergraduate study programs, except IEM	
Entry Requirements *Pre-requisites* ☒ None	*Co-requisites* ☒ None	*Knowledge, Abilities, or Skills* • The ability and openness to engage in interdisciplinary issues of global relevance • Media literacy, critical thinking, and a proficient handling of data sources	*Frequency* Annually (Spring) *Duration* 1 semester	*Forms of Learning and Teaching* • Lecture (17.5 hours) • Private study (45 hours) *Workload* 62.5 hours	
Recommendations for Preparation Critically following media coverage of the module's topics in question.					

Content and Educational Aims

All "Big Questions" (BQ) modules deal with the economic, technological, societal, and environmental contexts of the global issues and challenges of the coming decades. BQ modules intend to raise awareness of those challenges and broaden students' horizon with applied problem solving beyond the borders of their own disciplines. Knowledge and skills offered in the interdisciplinary BQ modules support students in their development to become informed and responsible citizens in a global society.
This module will give a brief introduction into the development of the atmosphere throughout Earth's history from the beginning of the geological record up to modern times, and will focus on geological, cosmogenic, and anthropogenic changes. Several major events in the evolution of the Earth that had a major impact on climate will be discussed, such as the evolution of an oxic atmosphere and ocean, the onset of early life, snowball Earth, and modern glaciation cycles. In the second part, the module will focus on the human impact on present climate change and global warming. Causes and consequences, including case studies and methods for studying climate change, will be presented and possibilities for climate mitigation (geo-engineering) and adapting our society to climate change (such as coastal protection and adaption of agricultural practices to more arid and hot conditions) will be discussed.

Intended Learning Outcomes

Students acquire transferable and key skills in this module.

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

- use their disciplinary factual and methodological knowledge to reflect on interdisciplinary questions by comparing approaches from various disciplines;
- advance a knowledge-based opinion on the complex module topics, including: impact of climate change on the natural environment over geological timescales and since the industrial revolution, and the policy framework in which environmental decisions are made internationally;
- work effectively in a team environment and undertake data interpretation;
- discuss approaches to minimize habitat destruction.

Indicative Literature

The course is based on a self-contained, detailed set of online lecture notes.

Ruddiman, William F. Earth's Climate (2001). Past and future. New York: Macmillan.

Usability and Relationship to other Modules

- This module is a mandatory elective module in the Big Questions area, which is part of the Jacobs Track (Methods and Skills modules; Community Impact Project module; Language modules; Big Questions modules).
- Students are encouraged to relate the content of their previous modules to the topics of this module and contribute their knowledge and competencies to class discussions and activities.

Assessment

Type: Written examination	Duration: 60 min.
Scope: All intended learning outcomes of the module	Weight: 100%

7.23.2.7 Extreme Natural Hazards, Disaster Risks, and Societal Impact

<table>
<tr><td colspan="3">Module Name
Big Questions: Extreme Natural Hazards, Disaster Risks, and Societal Impact</td><td>Module Code
JTBQ-08</td><td>Level (type)
Year 3 (Jacobs Track)</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>JTBQ-08</td><td colspan="3">Extreme Natural Hazards: Disaster Risks, and Societal Impact</td><td>Lecture</td><td>2.5</td></tr>
<tr><td>Module Coordinator

L. Thomsen</td><td colspan="3">Program Affiliation

• Big Questions Area: All undergraduate study programs, except IEM</td><td colspan="2">Mandatory Status

• Mandatory elective for students of all undergraduate study programs, except IEM</td></tr>
<tr><td rowspan="2">Entry Requirements

Pre-requisites

☒ None</td><td rowspan="2">Co-requisites

☒ None</td><td rowspan="2">Knowledge, Abilities, or Skills

• The ability and openness to engage in interdisciplinary issues of global relevance
• Media literacy, critical thinking, and a proficient handling of data sources</td><td>Frequency

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

• Lecture (17.5 hours)
• Private study (45 hours)</td></tr>
<tr><td>Duration

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

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

Critically following media coverage of the module’s topics in question.</td></tr>
<tr><td colspan="6">Content and Educational Aims

All “Big Questions” (BQ) modules deal with the economic, technological, societal, and environmental contexts of the global issues and challenges of the coming decades. BQ modules intend to raise awareness of those challenges and broaden students’ horizons with applied problem solving beyond the borders of their own disciplines. Knowledge and skills offered in the interdisciplinary BQ modules support students in their development to become informed and responsible citizens in a global society.
Extreme natural events increasingly dominate global headlines, and understanding their causes, risks, and impacts, as well as the costs of their mitigation, is essential to managing hazard risk and saving lives. This module presents a unique, interdisciplinary approach to disaster risk research, combining natural science and social science methodologies. It presents the risks of global hazards and natural disasters such as volcanoes, earthquakes, landslides, hurricanes, precipitation floods, and space weather, and provides real-world hazard and disaster case studies from Latin America, the Caribbean, Africa, the Middle East, Asia, and the Pacific.</td></tr>
<tr><td colspan="6">Intended Learning Outcomes

Students acquire transferable and key skills in this module.

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

• use their disciplinary factual and methodological knowledge to reflect on interdisciplinary questions by comparing approaches from various disciplines;
• advance a knowledge-based opinion on the complex module topics, including how natural processes affect and interact with our civilization, especially those that create hazards and disasters;
• distinguish the methods scientists use to predict and assess the risk of natural disasters;</td></tr>
</table>

- discuss the social implications and policy framework in which decisions are made to manage natural disasters;
- work effectively in a team environment.

Indicative Literature

The course is based on a self-contained, detailed set of online lecture notes.

Ismail-Zadeh, Alik, et al., eds (2014). Extreme natural hazards, disaster risks and societal implications. In *Special Publications of the International Union of Geodesy and Geophysics Vol. 1.* Cambridge: Cambridge University Press.

Usability and Relationship to other Modules

- The module is a mandatory elective module of the Big Questions area, that is part of the Jacobs Track (Methods and Skills modules; Community Impact Project module; Language modules; Big Questions modules)
- Students are encouraged to relate the content of their previous modules to the topics of this module and contribute such knowledge and competences to class discussions and activities.

Assessment

Type: Written examination | Duration: 60 min.
Scope: All intended learning outcomes of the module | Weight: 100%

7.23.2.8 International Development Policy

<table>
<tr><td colspan="3">Module Name
Big Questions: International Development Policy</td><td>Module Code
JTBQ-09</td><td>Level (type)
Year 3 (Jacobs Track)</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>JTBQ-09</td><td colspan="3">Big Questions: International Development Policy</td><td>Lecture</td><td>2.5</td></tr>
<tr><td>Module Coordinator

C. Knoop</td><td colspan="3">Program Affiliation

• Big Questions Area: All undergraduate study programs, except IEM</td><td colspan="2">Mandatory Status

• Mandatory elective for students of all undergraduate study programs, except IEM</td></tr>
<tr><td rowspan="2">Entry Requirements

Pre-requisites

☒ None</td><td rowspan="2">

Co-requisites

☒ None</td><td rowspan="2">

Knowledge, Abilities, or Skills

• The ability and openness to engage in interdisciplinary issues of global relevance
• Media literacy, critical thinking, and a proficient handling of data sources</td><td>Frequency

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

• Lecture (17.5 hours)
• Presentations
• Private study (45 hours)</td></tr>
<tr><td>Duration

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

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

Critically following media coverage of the module’s topics in question.</td></tr>
<tr><td colspan="6">Content and Educational Aims

All “Big Questions” (BQ) modules deal with the economic, technological, societal, and environmental contexts of the global issues and challenges of the coming decades. BQ modules intend to raise awareness of those challenges and broaden students’ horizon with applied problem solving beyond the borders of their own disciplines. Knowledge and skills offered in the interdisciplinary BQ modules support students in their development to become informed and responsible citizens in a global society.
We live in a world where still a large number of people still live in absolute poverty without access to basic needs and services, such as food, sanitation, health care, security, and proper education. This module provides an introduction to the basic elements of international development policy, with a focus on the relevant EU policies in this field and on the Sustainable Development Goals/SDGs of the United Nations. The students will not only learn about the tools applied in modern development policies, but also about the critical aspects of monitoring and evaluating the results of development policy. Module-related oral presentations and debates will enhance the students’ learning experience.</td></tr>
</table>

Intended Learning Outcomes

Students acquire transferable and key skills in this module.

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

- use their disciplinary factual and methodological knowledge to reflect on interdisciplinary questions by comparing approaches from various disciplines;
- breakdown the complexity of modern development policy;
- identify, explain, and evaluate the tools applied in development policy;
- formulate well-justified criticism of development policy;
- summarize and present a module-related topic in an appropriate verbal and visual form.

Indicative Literature

Francis Fukuyama (2006). The end of history and the last man. New York: Free Press.

Kingsbury, McKay, Hunt (2008). International Development.Issues and challenges. London: Palgrave.

A.Sumner, M.Tiwari (2009) After 2015: International Development Policy at a crossroad. New York: Palgrave Macmillan.

Graduate Institute of International Development, G. Carbonnier eds. (2001). International Development Policy: Energy and Development. New York:Palgrave Macmillan.

John Donald McNeil. International Development: Challenges and Controversy. Sentia Publishing,e-book.

Usability and Relationship to other Modules

- This module is a mandatory elective module in the Big Questions area, which is part of the Jacobs Track (Methods and Skills modules; Community Impact Project module; Language modules; Big Questions modules).
- Students are encouraged to relate the content of their previous modules to the topics of this module and contribute their knowledge and competencies to class discussions and activities.

Assessment

Type: Presentation
Scope: All intended learning outcomes of the module

Duration: 10 minutes per student
Weight: 100%

7.23.2.9 Sustainable Value Creation with Biotechnology. From Science to Business

Module Name			*Module Code*	*Level (type)*	*CP*
Sustainable Value Creation with Biotechnology. From Science to Business.			JTBQ-BQ-011	Year 3 (Jacobs Track)	2.5
Module Components					
Number	*Name*			*Type*	*CP*
JTBQ-011	Sustainable Value Creation with Biotechnology. From Science to Business			Lecture - Tutorial	2.5
Module Coordinator Marcelo Fernandez Lahore	*Program Affiliation* • Jacobs Track - Big Questions			*Mandatory Status* • Mandatory elective for students of all undergraduate study except IEM	
Entry Requirements *Pre-requisites* ☒ None	*Co-requisites* ☒ None	*Knowledge, Abilities, or Skills* • The ability and openness to engage in interdisciplinary issues on bio-based value creation • media literacy, critical thinking and a proficient handling of data sources	*Frequency* Annually (Spring)	*Forms of Learning and Teaching* • Lecture and Tutorial (17.5 hours) • Private study (45 hours)	
			Duration 1 semester	*Workload* 62.5 hours	
Recommendations for Preparation https://www.ctsi.ucla.edu/researcher-resources/files/view/docs/EGBS4_Kolchinsky.pdf https://link.springer.com/article/10.1057/jcb.2008.27 https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf					

Content and Educational Aims

All "Big Questions" (BQ) modules deal with the economic, technological, societal and environmental contexts of the global issues and challenges of the coming decades. The BQ modules intend to raise awareness of those challenges and broaden the students' horizon with applied problem solving beyond the borders of their own disciplines. Knowledge and skills offered in the interdisciplinary BQ modules support students in their development to become an informed and responsible citizen in a global society.
This module has a particular focus on the role that Biotechnology and Biorefining is expected to play in social, economic and environmental contexts.

To deliver such a vision the module will prepare students to extract value form Biotechnology and associated activities. This will be done in the form of business cases that will be systematically developed by students alongside the development of the module. In this way, students will develop entrepreneurial skills while understanding basic business-related activities that are not always present in a technical curriculum. Case development will also provide students with the possibility of understanding the social, economic, environmental impact that Biotechnology and Biorefining can deliver in a Bio-Based Economy. The knowledge and skills gained through this module are in direct and indirect support of the UN 2030 Agenda for Sustainable Development: "Transforming our World".

Intended Learning Outcomes

Students acquire transferable and key skills in this module.

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

1. design and develop a Business Case based on the tools provided by modern Biotechnology;
2. explain the interplay between Science, Technology and Economics / Finance;
3. use their disciplinary factual and methodological knowledge to reflect on interdisciplinary questions by comparing approaches from various disciplines;
4. work effectively in a team environment and undertake data interpretation and analysis;
5. discuss approaches to value creation in the context of Biotechnology and Sustainable Development;
6. explain the ethical implications of technological advance and implementation;
7. demonstrate presentation skills.

Indicative Literature

Springham, D., V. Moses & R.E. Cape (1999). Biotechnology – The Science and the Business. 2nd. Ed. Boca Raton: CRC Press.

Kornberg, Arthur (2002). The Golden Helix: Inside Biotech Ventures. Sausalito, CA: University Science Books.

UNESCO, Director-General. (2017). UNESCO moving forward the 2030 Agenda for Sustainable Development. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000247785

Usability and Relationship to other Modules

- The module is a mandatory elective module in the Big Questions area, which is part of the Jacobs Track (Methods and Skills modules; Community Impact Project module; Language modules; Big Questions modules).
- Students are encouraged to relate the content of their previous modules to the topics of this module and contribute their knowledge and competencies to class discussions and activities.

Assessment

Type: Term Paper — Length:1.500 – 3.000 words, Weight: 75%

Scope: Intended learning outcomes of the module (1-6)

Type: Presentation — Duration: 10-15 min., Weight: 25%

Scope: Intended learning outcomes of the module (2-7)

7.23.2.10 Gender and Multiculturalism. Debates and Trends in Contemporary Societies

Module Name			*Module Code*	*Level (type)*	*CP*
Big Questions: Gender and Multiculturalism. Debates and Trends in Contemporary Societies			JT-BQ-013	Year 3 (Jacobs Track)	5.0
Module Components					
Number	*Name*			*Type*	*CP*
JT-BQ-013	Gender and Multiculturalism: Debates and Trends in Contemporary Societies			Lecture	5.0
Module Coordinator J. Price	*Program Affiliation* • Big Questions Area: All undergraduate study programs			*Mandatory Status* Mandatory elective for students of all undergraduate study programs	
Entry Requirements			*Frequency* Annually (Spring)	*Forms of Learning and Teaching* • Lectures (35 hours) • Private study (90 hours)	
Pre-requisites ☒ None	*Co-requisites* ☒ None	*Knowledge, Abilities, or Skills* • The ability and openness to engage in interdisciplinary issues of global relevance • Media literacy, critical thinking and a proficient handling of data sources	*Duration* 1 semester	*Workload* 125 hours	
Recommendations for Preparation Critical following of the media coverage on the module's topics in question.					
Content and Educational Aims All "Big Questions" (BQ) modules deal with the economic, technological, societal and environmental contexts of the global issues and challenges of the coming decades. The BQ modules intend to raise awareness of those challenges and broaden the students' horizon with applied problem solving beyond the borders of their own disciplines. Knowledge and skills offered in the interdisciplinary BQ modules are relevant for every university graduate in order to become an informed and responsible citizen in a global society. The objective of this module is to introduce and familiarize students with the current debates, trends and analytical frameworks pertaining how gender is socially constructed in different cultural zones. Through lectures, group discussions and reflecting upon cultural cases, students will familiarize themselves with the current trends and the different sides of ongoing cultural and political debates that shape cultural practices, policies and discourses. The module will zoom-in on topics such as: cultural identity; the social construction of gender; gender fluidity and its backlash; gender and human rights; multiculturalism as a perceived threat in plural societies, among others. Students will be provided with opportunities for reflection and to ultimately develop informed opinions concerning topics that are continue to define some of the most contested cultural debates of contemporary societies.					

Intended Learning Outcomes

Students acquire transferable and key skills in this module.

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

- use their disciplinary factual and methodological knowledge to reflect on interdisciplinary questions by comparing approaches from various disciplines;
- summarize and evaluate the current cultural, political and legal debates concerning the social construction of gender in contemporary societies;
- reflect and develop informed opinions concerning the current debates and trends that are shaping ideas of whether multiculturalism ideals are realistic in pluralist western societies, or whether multiculturalism is a failed project;
- identify, explain and evaluate the role that societal forces, such as religion, socio-economic, political and migratory factors play in the construction of gendered structures in contemporary societies
- develop a well-informed perspective concerning the interplay of science and culture in the debates around gender fluidity.
- deconstruct and reflect on the intersectionality between populist/nationalist discourses and gender discrimination
- reflect and propose societal strategies and initiatives that attempt to answer the big questions presented in this module regarding gendered and cross-culturally-based inequalities.

Indicative Literature

Moller Okin, S. (1999). Is Multiculturalism Bad for Women? New Jersey: Princeton University Press.

Connell, R. W. (2002). Gender. Cambridge: Polity Press.

Inglehart, Ronald and Pippa Norris (2003). Rising Tide: Gender Equality and Cultural Change Around the World. New York and Cambridge: Cambridge University Press.

Usability and Relationship to other Modules

- The module is a mandatory elective module of the Big Questions area, that is part of the Jacobs Track (Methods and Skills modules; Community Impact Project module; Language modules; Big Questions modules)
- Students are encouraged to relate the content of their previous modules to the topics of this module and contribute such knowledge and competences to class discussions and activities.

Assessment

Type: Written examination — Duration: 60 min. Weight: 100%

Scope: All intended learning outcomes of the module

7.23.2.11 Big Questions: The Challenge of Sustainable Energy

Module Name	*Module Code*	*Level (type)*	*ECTS*
Big Questions: The Challenge of Sustainable Energy	JTBQ-14	Year 3 (Jacobs Track)	2.5

Module Components

Number		*Type*	*ECTS*
JTBQ-14	The Challenge of Sustainable Energy	Lecture	2.5

Module Coordinator	*Program Affiliation*	*Mandatory Status*
K. Smith Stegen	• Big Questions Area: All undergraduate study programs	Mandatory elective for students of all undergraduate study programs

Entry Requirements

Pre-requisites	*Co-requisites*	*Knowledge, Abilities, or Skills*	*Frequency*	*Forms of Learning and Teaching*
☒ None	☒ None	• Ability to read texts from a variety of disciplines	Annually (Fall or Spring)	• Lectures and Group Exercises
			Duration	*Workload*
			1 semester	62.5 hours

Recommendations for Preparation

Reflect on their own behavior and habits with regard to sustainability.

Content and Educational Aims

All "Big Questions" (BQ) modules deal with the economic, technological, societal and environmental contexts of the global issues and challenges of the coming decades. The BQ modules intend to raise awareness of those challenges and broaden the students' horizon with applied problem solving beyond the borders of their own disciplines. Knowledge and skills offered in the interdisciplinary BQ modules are relevant for every university graduate in order to become an informed and responsible citizen in a global society.

How can wide-scale social, economic and political change be achieved? This module examines this question in the context of encouraging "sustainability". To address global warming and environmental degradation, humans must adopt more sustainable lifestyles. Arguably, the most important change is the transition from conventional fuels to renewable sources of energy, particularly at the local, country and regional levels. The main challenge to achieving an "energy transition" stems from human behavior and not from a lack of technology or scientific expertise. This module thus examines energy transitions from the perspective of the social sciences, including political science, sociology, psychology, economics and management. To understand the drivers of and obstacles to technology transitions, students will learn the "Multi-Level Perspective". Some of the key questions explored in this module include: What is meant by sustainability? Are renewable energies "sustainable"? How can a transition to renewable energies be encouraged? What are the main social, economic, and political challenges? How can these (potentially) be overcome? The aim of the course is to provide students with the tools for reflecting on energy transitions from multiple perspectives.

Intended Learning Outcomes

Students acquire transferable and key skills in this module.

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

- articulate the history of the sustainability movement and the major debates;
- identify different types of renewable energies;
- explain the multi-level perspective (MLP), which models technology innovations and transitions;
- summarize the obstacles to energy transitions;
- compare a variety of policy mechanisms for encouraging renewable energies.

Usability and Relationship to other Modules
• The module is a mandatory elective module of the Big Questions area that is part of the Jacobs Track (Methods and Skills modules; Community Impact Project module; Language modules; Big Questions modules). • For students interested in sustainability issues, this module complements a variety of modules from different programs, such as "International Resource Politics" (IRPH/ISS), "Environmental Science" (EES), "General Earth and Environmental Sciences" (EES), and "Renewable Energies" (Physics).
Assessment Type: Written Examination Duration: 60 min Weight: 100% Scope: All intended learning outcomes of the module

7.23.2.12 Big Questions: State, Religion and Secularism

Module Name			*Module Code*	*Level (type)*	*CP*
Big Questions: State, Religion and Secularism			JTBQ-15	Year 3 (Jacobs Track)	2.5
Module Components					
Number				*Type*	*CP*
JTBQ-15	State, religion and secularism			Lecture	2.5
Module Coordinator Manfred O. Hinz	*Program Affiliation* • Big Questions Area: All undergraduate study programs			*Mandatory Status* Mandatory elective for students of all undergraduate study programs, except IEM	
Entry Requirements *Pre-requisites* ☒ None	*Co-requisites* ☒ None	*Knowledge, Abilities, or Skills* • Ability to read texts from a variety of disciplines		*Frequency* Annually (Fall or Spring)	*Forms of Learning and Teaching* • Lectures and Group Exercises
				Duration 1 semester	*Workload* 62.5 Hours

Recommendations for Preparation

Reflect on the situation and role in respective home-country

Content and Educational Aims

The relationship between state and religion has been a matter of concern in most if not all societies. Is religion above the state, or is it to the state to determine the place of religion? What does secularity mean? To what extent will religion accept secularity? Where does the idea of secularity come from? The course State, religion, secularism will search for answers to questions of this nature. After introducing to the topic and looking at some legal attempts to regulate the relationship between state and religion, the focus will be, on the one hand, on Christianity and secularity and, on Islam and secularity, on the other. Depending on the interest of participants, other religions and their relationships to states of relevance can be added.

Intended Learning Outcomes

By the end of this course, students should be able

- To understand the basic problems that have led to different models to regulate the relationship between the state and religion;
- To reflect critically the situation of state and religion in selected countries;
- To assess the values behind the concept of democracy and human rights;
- To use the acquired knowledge to strengthen the capacity towards respect for others and tolerance.

Usability and Relationship to other Modules

- The module is a mandatory elective module of the Big Questions area that is part of the Jacobs Track (Methods and Skills modules; Community Impact Project module; Language modules; Big Questions modules).
- For students interested in State, Religion and secularism, this module complements modules from other programmes, such as IRPH and ISS

Examination Type: Module Examination

Assessment Type: Term paper — Length:1.500 – 3.000 words
Weight: 100%

Scope: All intended learning outcomes of the module.

7.23.3 Community Impact Project

Module Name			*Module Code*	*Level (type)*	*CP*
Community Impact Project			JTCI-CI-950	Year 3 (Jacobs Track)	*5*
Module Components					
Number	*Name*			*Type*	*CP*
JTCI-950	Community Impact Project			Project	5
Module Coordinator CIP Faculty Coordinator	*Program Affiliation* • All undergraduate study programs except IEM			*Mandatory Status* Mandatory for all undergraduate study programs except IEM	
Entry Requirements *Pre-requisites* ☒ at least 15 CP from CORE modules in the major	*Co-requisites* ☒ None	*Knowledge, Abilities, or Skills* • Basic knowledge of the main concepts and methodological instruments of the respective disciplines	*Frequency* Annually (Spring)	*Forms of Learning and Teaching* • Introductory, accompanying, and final events: 10 hours • Self-organized teamwork and/or practical work in the community: 115 hours	
			Duration 1 semester	*Workload* 125 hours	
Recommendations for Preparation Develop or join a community impact project before the 5th 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 their 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 Jacobs as socially conscious and responsible graduates (part of the Jacobs					

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 should 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;
- ability to work in a team and deal with diversity, develop cooperation and conflict skills, and strengthen their empathy and tolerance for ambiguity.

Indicative Literature

Not specified

Usability and Relationship to other Modules

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

Assessment

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

7.23.4 Language Modules

The descriptions of the language modules are provided in a separate document, the "Language Module Handbook" that can be accessed from here: https://www.jacobs-university.de/study/learning-languages

8 Appendix

8.1 Intended Learning Outcomes Assessment-Matrix

Mathematics BSc					Analysis I	Linear Algebra	Applied Mathematics	Introductory Algebra	Analysis III	Seminar	Dynamical Systems Lab/Stochastic Methods Lab	Specialization Modules (choose 5-8 Modules)	Bachelor Thesis	Calculus and Elements of Linear Algebra 1	Calculus and Elements of Linear Algebra 2	Probability and Random Processes	Numerical Methods	Internship	JT Triangle 1	JT Triangle 2	Community Impact	JT Language	JT Language	JT Language	JT Language
Semester					1	2	1	3	4	3	4	3-6	6	1	2	3	4	5	5/6	5/6	5	1	2	3	4
Mandatory/mandatory elective					m	m	m	m	m	m	me	me	m	m	m	m	m	m	me	me	m	me	me	me	me
Credits					7.5	7.5	7.5	7.5	7.5	5	7.5	5	15	5	5	5	5	15	5	5	5	2.5	2.5	2.5	2.5
	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								
Recognize patterns and discover underlying principles	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 worldwide	x	x			x	x	x	x	x					x	x	x	x								
Independently perform simple proofs and derivations in these fields and know the principles behind more complicated proofs and derivations	x	x			x	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													
Write simple programs in at least one programming language	x	x					x				x	(x)	(x)				x								
Have basic knowledge about standard mathematical software packages and use them productively in everyday problem solving	x	x					x				x	(x)	(x)												
Formulate mathematical ideas in written text	x	x			(x)	(x)	(x)	(x)	(x)	x	(x)	(x)	x	(x)	(x)	(x)	(x)								
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)				
Present complex ideas to specialists and non-specialists	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)				
Possess generic problem solving skills, including a sense of figuring out 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				
Work effectively in a diverse team and to take responsibility in a team		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	(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				
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)				
Take on responsibility in a diverse team	x	x	x	x						(x)	(x)							x	x	x	x	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	x
Assessment Type																									
Oral examination																									
Final written exam					x	x	x	x	x			x		x	x	x	x					x	x	x	x
Project portfolio											x										x				
Essay																									
(Lab) report																		x							
Poster presentation																									
Presentation										x			x												
Thesis													x												
Module achievements/bonus achievements					x	x	x	x	x			x		x	x	x	x								

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

Figure 4: Intended Learning Outcomes Assessment-Matrix