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).

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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 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 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. Specific Advantages of Mathematics at Jacobs University

1.2 Specific Advantages of Mathematics at Jacobs University

The key element in our education is that we do not just 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,
• 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 worldwide,
• 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:

• write simple programs in at least one programming language,
• have basic knowledge about standard mathematical software packages and use them productively in everyday problem solving,
• formulate mathematical ideas in written text,
• 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, and
• 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,
• demonstrate a sense for the use of Mathematics in one or more fields of application.

Finally, graduates possess the following Subject-independent Skills:

• engage ethically with academic and professional communities, and with the general public to actively contribute to a sustainable future, reflecting and respecting different views,

1.3 Career Options

There are few undergraduate degrees which rival mathematics in the diversity of rewarding job options, which include the following:
• Insurance companies hire mathematicians on 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 rewarding careers after their time at Jacobs University. Furthermore, the Alumni Office helps students establish a long-lasting and worldwide network which comes in handy 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

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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 undergraduate program involves six semesters of study with a total of 180 ECTS credit points (CP). The undergraduate curricular structure follows an innovative and student-centered modularization scheme - the 3C-Model - that groups the disciplinary content of the three study years according to overarching themes:

2.2.1 Year 1 – CHOICE

The first study year is characterized by a university-specific offering of disciplinary education that builds on and expands upon the students’ entrance qualifications. Students select introductory modules for a total of 45 CP from the CHOICE area of a variety of study programs, of which 15-30 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

Figure 1: The Jacobs University 3C-Model
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 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 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 studies according to interest and with the aim to allow a change of major until the beginning of the second year, when the major becomes fixed.

### 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 that 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:

- **Electrical and Computer Engineering (ECE)**
  - CHOICE Module: General Electrical Engineering I (7.5 CP)
  - CHOICE Module: General Electrical Engineering II (7.5 CP)

- **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 (7.5 CP)
  - 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 which 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 early; 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 taken:

- CORE Module: Undergraduate Seminar (5 CP, Semester 3+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 2nd/3rd year CORE and Specialization modules¹:

- 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 studies according to interest and 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, 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 the students’ knowledge and skills, support the 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 and
- 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 about their career path after graduation. To explore available choices and to gain professional experience, students undertake a mandatory summer internship. The third year of studies allows Math 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 also opens a mobility window for a diverse range of study abroad options. Finally, the 6th semester is dedicated to fostering the students’ research experience by involving them in an extended Bachelor thesis project.

2.2.3.1 Internship / Start-up and Career Skills Module

As a core element of 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 (http://www.jacobs-university.de/career-services/contact).

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 major, students take further 15 CP from mandatory elective Specialization modules:

- 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 between 10-15 CP of major-specific Specialization modules and between 5-15 CP of modules equivalent to the non-

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2 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."
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 modules.

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 Linear Algebra I (5 CP)
• Methods: Calculus and 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 the 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 Linear Algebra I (5 CP)
- Methods Module: Calculus and 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 case of a conflict between the regulations in this handbook and the general Policies for Bachelor Studies, the latter apply (see [http://www.jacobs-university.de/academic-policies](http://www.jacobs-university.de/academic-policies)).

Jacobs University Bremen reserves the right to substitute modules by replacements and/or reduce the number of mandatory/mandatory-elective modules offered.

#### 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.
Figure 2 shows schematically 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 Plans in the following section.
### Mathematics BSc

#### Matriculation Fall 2019

<table>
<thead>
<tr>
<th>Program-Specific Modules</th>
<th>Type</th>
<th>Assessment</th>
<th>Period</th>
<th>Status¹</th>
<th>Sem.</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jacobs Track Modules (General Education)</td>
<td>Type</td>
<td>Assessment</td>
<td>Period</td>
<td>Status²/ Sem.</td>
<td>CP</td>
<td></td>
</tr>
</tbody>
</table>

#### Year 1 - CHOICE

- Take the mandatory CHOICE module listed below. This is a requirement for the Math program.
- 15 CP

<table>
<thead>
<tr>
<th>Module: Mathematical Foundations (default minor)</th>
<th>Type</th>
<th>Assessment</th>
<th>Period</th>
<th>Status¹</th>
<th>Sem.</th>
<th>CP</th>
</tr>
</thead>
</table>

#### Year 2 - CORE

- Take all modules listed below or replace mandatory electives (“me”) modules (15 CP) with suitable CORE modules from other study programs.
- 45 CP

<table>
<thead>
<tr>
<th>Module: Number Theory</th>
<th>Type</th>
<th>Assessment</th>
<th>Period</th>
<th>Status¹</th>
<th>Sem.</th>
<th>CP</th>
</tr>
</thead>
</table>

#### Year 3 - CAREER

- 45 CP

<table>
<thead>
<tr>
<th>Module: Internship/Startup and Career Skills</th>
<th>Type</th>
<th>Assessment</th>
<th>Period</th>
<th>Status¹</th>
<th>Sem.</th>
<th>CP</th>
</tr>
</thead>
</table>

#### Year 4 - Interdisciplinary Modules

- 15 CP

<table>
<thead>
<tr>
<th>Module: Social Sciences</th>
<th>Type</th>
<th>Assessment</th>
<th>Period</th>
<th>Status¹</th>
<th>Sem.</th>
<th>CP</th>
</tr>
</thead>
</table>

#### Study and Examination Plan

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

### Jacobs Track Modules (General Education)

<table>
<thead>
<tr>
<th>Module: Calculus and Linear Algebra</th>
<th>Type</th>
<th>Assessment</th>
<th>Period</th>
<th>Status¹</th>
<th>Sem.</th>
<th>CP</th>
</tr>
</thead>
</table>

### Unit: Language

- German is default language. Native German speakers take modules in another offered language.

### Unit: Methods / Skills

- 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.

### Unit: Profile Mathematics or Minor Study Program

- 15 CP

### Unit: Core Mathematics

- 15 CP

### Unit: Foundations of Mathematics

- 15 CP

### Unit: CHOICE (own selection)

- 15 CP

### Unit: Mathematics BSc

- Matriculation Fall 2019

### Jacobs Track Modules (General Education)

- Type | Assessment | Period | Status¹ | Sem. | CP |

### Unit: Methods / Skills

- Type | Assessment | Period | Status¹ | Sem. | CP |

### Unit: Language

- Type | Assessment | Period | Status¹ | Sem. | CP |

### Unit: Methods / Skills

- Type | Assessment | Period | Status¹ | Sem. | CP |

### Unit: Language

- Type | Assessment | Period | Status¹ | Sem. | CP |

### Study and Examination Plan

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

### Jacobs Track Modules (General Education)

- Type | Assessment | Period | Status¹ | Sem. | CP |

### Unit: Methods / Skills

- Type | Assessment | Period | Status¹ | Sem. | CP |

### Unit: Language

- Type | Assessment | Period | Status¹ | Sem. | CP |

### Unit: Methods / Skills

- Type | Assessment | Period | Status¹ | Sem. | CP |

### Unit: Language

- Type | Assessment | Period | Status¹ | Sem. | CP |

### Study and Examination Plan

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

### Jacobs Track Modules (General Education)

- Type | Assessment | Period | Status¹ | Sem. | CP |

### Unit: Methods / Skills

- Type | Assessment | Period | Status¹ | Sem. | CP |

### Unit: Language

- Type | Assessment | Period | Status¹ | Sem. | CP |

### Unit: Methods / Skills

- Type | Assessment | Period | Status¹ | Sem. | CP |

### Unit: Language

- Type | Assessment | Period | Status¹ | Sem. | CP |

### Study and Examination Plan

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

### Jacobs Track Modules (General Education)

- Type | Assessment | Period | Status¹ | Sem. | CP |

### Unit: Methods / Skills

- Type | Assessment | Period | Status¹ | Sem. | CP |

### Unit: Language

- Type | Assessment | Period | Status¹ | Sem. | CP |

### Unit: Methods / Skills

- Type | Assessment | Period | Status¹ | Sem. | CP |

### Unit: Language

- Type | Assessment | Period | Status¹ | Sem. | CP |
7 Module Descriptions

7.1 Analysis I

<table>
<thead>
<tr>
<th>Module Name</th>
<th>Module Code</th>
<th>Level (type)</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis I</td>
<td>CH-200</td>
<td>Year 1 (CHOICE)</td>
<td>7.5</td>
</tr>
</tbody>
</table>

Module Components

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Type</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH-200-A</td>
<td>Analysis I</td>
<td>Lecture</td>
<td>5</td>
</tr>
<tr>
<td>CH-200-B</td>
<td>Analysis I Tutorial</td>
<td>Tutorial</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Module Coordinator

S. Petrat

Program Affiliation

• Mathematics

Mandatory Status

Mandatory for Mathematics

Entry Requirements

Pre-requisites

• None

Co-requisites

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

Frequency

Annually

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

• It is recommended to co-enroll into the Methods module “Calculus and Linear Algebra I”
• Revise your high school mathematics
• Read general interest expositions about mathematics and mathematicians
• Work 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

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

### Intended Learning Outcomes
By the end of the module, students will be able to
- cleanly formulate mathematical concepts and results which arise in the class room
- outline proofs in a clear way of results which have been proved in the lectures
- to independently prove results which are direct consequences of those proved in the lectures
- understand and use fundamental mathematical terminology to communicate mathematics at university level

### 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” in the following way: “Calculus and 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.

### Assessment
In all module descriptions the category “Assessment” describes the requirements for the award of ECTS credit points (CP) for the respective module.

<table>
<thead>
<tr>
<th>Type: Written examination</th>
<th>Duration: 120 min</th>
<th>Weight: 100%</th>
</tr>
</thead>
</table>

Scope: All intended learning outcomes of this module.

Additional bonus homework as a voluntary task can improve the grade by 0.33 points (German grading system) but is not required to reach the best grade in the module (1.0).
7.2 Linear Algebra

<table>
<thead>
<tr>
<th>Module Name</th>
<th>Module Code</th>
<th>Level (type)</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear Algebra</td>
<td>CH-201</td>
<td>Year 1 [CHOICE]</td>
<td>7.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Module Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>CH-201-A</td>
</tr>
<tr>
<td>CH-201-B</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Module Coordinator</th>
<th>Program Affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Penkov</td>
<td>Mathematics</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Entry Requirements</th>
<th>Knowledge, Abilities, or Skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-requisites</td>
<td>None</td>
</tr>
<tr>
<td>Co-requisites</td>
<td>None</td>
</tr>
<tr>
<td>- Basic matrix algebra at the level achieved in “Calculus and Elements of Linear Algebra I”</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Forms of Learning and Teaching</th>
</tr>
</thead>
<tbody>
<tr>
<td>annually</td>
<td>Lectures (35 hours)</td>
</tr>
<tr>
<td></td>
<td>Tutorials (17.5 hours)</td>
</tr>
<tr>
<td></td>
<td>Private Study (135 hours)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Duration</th>
<th>Workload</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 semester</td>
<td>187.5 hours</td>
</tr>
</tbody>
</table>

**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

**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
## 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

## 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.

## Assessment

<table>
<thead>
<tr>
<th>Type: Written examination</th>
<th>Duration: 120 min</th>
<th>Weight: 100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scope: All intended learning outcomes of this module</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Additional bonus homework as a voluntary task can improve the grade by 0.33 points (German grading system) but is not required to reach the best grade in the module (1.0).
7.3 Applied Mathematics

<table>
<thead>
<tr>
<th>Module Name</th>
<th>Module Code</th>
<th>Level (type)</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied Mathematics</td>
<td>CH-202</td>
<td>Year 1 (CHOICE)</td>
<td>7.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Module Components</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Type</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH-202-A</td>
<td>Advanced Calculus and Methods of Mathematical Physics</td>
<td>Lecture</td>
<td>5</td>
</tr>
<tr>
<td>Ch-202-B</td>
<td>Numerical Software Lab</td>
<td>Lab</td>
<td>2.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Module Coordinator</th>
</tr>
</thead>
</table>

Marcel Oliver
Ulrich Kleinekathöfer

<table>
<thead>
<tr>
<th>Program Affiliation</th>
</tr>
</thead>
</table>

- Mathematics

<table>
<thead>
<tr>
<th>Mandatory Status</th>
</tr>
</thead>
</table>

Mandatory for Mathematics
Mandatory elective for ECE and Physics

<table>
<thead>
<tr>
<th>Entry Requirements</th>
</tr>
</thead>
</table>

Pre-requisites: None
Co-requisites: None

<table>
<thead>
<tr>
<th>Knowledge, Abilities, or Skills</th>
</tr>
</thead>
</table>

- Single-variable Calculus at the level achieved in “Calculus and Elements of Linear Algebra I”

<table>
<thead>
<tr>
<th>Frequency</th>
</tr>
</thead>
</table>

Annually

<table>
<thead>
<tr>
<th>Forms of Learning and Teaching</th>
</tr>
</thead>
</table>

- Lectures (35 hours)
- Lab (17.5 hours)
- Private Study (135 hours)

<table>
<thead>
<tr>
<th>Duration</th>
</tr>
</thead>
</table>

1 semester

<table>
<thead>
<tr>
<th>Workload</th>
</tr>
</thead>
</table>

187.5 hours

Recommendations for Preparation

Recapitulate single variable Calculus at a level of at least “Calculus and Elements of Linear Algebra I”

Content and Educational Aims

This module covers advanced topics from calculus which are part of the core mathematics education of every Physicist and also form 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, line integrals
- The Gauss and Stokes integral theorems
- Change of variables, integration in polar coordinates
- Fourier integrals + distributions
- Applications to partial differential equations important in physics (Laplace, Poisson, diffusion, wave equations)
- Very brief introduction to complex analysis (Cauchy formula + 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, fast Fourier transform)
- Visualization using Matplotlib, including a general introduction to 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.

**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 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

**Assessment**

Type: Written examination, Duration: 120 min, Weight: 70%
Scope: Intended learning outcomes of the lecture (5, 7).

Type: Lab report, Length: approx. 30 pages, Weight: 30%
Scope: Intended learning outcomes of the lab (1-6).

Additional bonus homework as a voluntary task can improve the grade by 0.33 points (German grading system) but is not required to reach the best grade in the module (1.0).
### 7.4 Number Theory

<table>
<thead>
<tr>
<th>Module Name</th>
<th>Module Code</th>
<th>Level (type)</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number Theory</td>
<td>CO-500</td>
<td>Year 2/3 (CORE)</td>
<td>5.0</td>
</tr>
</tbody>
</table>

#### Module Components

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Type</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO-500-A</td>
<td>Number Theory</td>
<td>Lecture</td>
<td>5.0</td>
</tr>
</tbody>
</table>

#### Module Coordinator

**K. Mallahi-Karai**

**Program Affiliation**

- Mathematics

**Mandatory Status**

Mandatory elective for Mathematics

#### 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

Annual

#### Forms of Learning and Teaching

- Lectures (35 hours)
- Private Study (90 hours)

#### Duration

1 semester

#### Workload

125 hours

#### Recommendations for Preparation

It is recommended to have taken the Methods module: Calculus and Linear Algebra I + II

Some basic familiarity with linear algebra is useful, but not technically required.

### Content and Educational Aims

This module is an elementary introduction to number theory, whose aim is to familiarize the audience with the classical ideas and methods of the field, as well as some of its more recent applications especially in cryptography and related technologies. Topics covered in this module include prime numbers and their distribution, the fundamental theorem of arithmetic, modular arithmetic, primitive roots, finite fields, applications to modern cryptography (e.g. RSA cryptographic platform), discrete logarithm problem, applications to error correcting codes, and quadratic reciprocity.

The second part of the module is more topical and deals with more advances topics such as Riemann Zeta function, primes in arithmetic progressions, continued fractions and diophantine approximations, Pell’s equation, Minkowski’s Geometry of numbers, the Gauss circle problem and related lattice point counting problems.
### Intended Learning Outcomes

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

- demonstrate their mastery of basic tools of number theory.
- develop ability to use number theoretic concepts and structures for applications in cryptographic platforms.
- analyse the definitions of basic number theoretic concepts such as primes numbers, congruences, finite fields.
- formulate and design methods and algorithms for solving applied problems using tools from number theory.

### 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.

### Assessment

<table>
<thead>
<tr>
<th>Type: Written examination</th>
<th>Duration: 120 min</th>
<th>Weight: 100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scope: All intended learning outcomes of this module</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Additional bonus homework as a voluntary task can improve the grade by 0.33 points (German grading system) but is not required to reach the best grade in the module (1.0).
7.5 Discrete Mathematics

<table>
<thead>
<tr>
<th>Module Name</th>
<th>Module Code</th>
<th>Level (type)</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discrete Mathematics</td>
<td>CO-501</td>
<td>Year 2/3 (CORE)</td>
<td>5.0</td>
</tr>
</tbody>
</table>

**Module Components**

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Type</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO-501-A</td>
<td>Discrete Mathematics</td>
<td>Lecture</td>
<td>5.0</td>
</tr>
</tbody>
</table>

**Module Coordinator**

K. Mallahi-Karai

**Program Affiliation**

- Mathematics

**Mandatory Status**

Mandatory elective for Mathematics and CS 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**

annual

**Forms of Learning and Teaching**

- Lectures (35 hours)
- Private Study (90 hours)

**Duration**

1 semester

**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 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 lecture emphasizes connections of discrete mathematics with other areas of mathematics such as linear algebra and basic probability, and outlines applications to areas of computer science, cryptography, etc. Where employment of ideas from discrete mathematics has proven to be fruitful. The first part of the lecture—enumerative combinatorics—deals with several classical enumeration problems (Binomial coefficients, Stirling numbers), counting under group actions and generating function. The second half of the lecture—graph theory—includes a discussion of basic notions such as chromatic number, planarity, matchings in graphs, Ramsey theory, and expanders, and their applications.
**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 and algorithms for solving applied problems based on concepts from discrete mathematics.

**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 and IMS.
- This module is a good option as an elective module for students in IMS.

**Assessment**

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

Scope: All intended learning outcomes of this module

Additional bonus homework as a voluntary task can improve the grade by 0.33 points (German grading system) but is not required to reach the best grade in the module (1.0).
## 7.6 Undergraduate Seminar

<table>
<thead>
<tr>
<th>Module Name</th>
<th>Module Code</th>
<th>Level (type)</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undergraduate Seminar</td>
<td>CO-502</td>
<td>Year 2 (CORE)</td>
<td>5</td>
</tr>
</tbody>
</table>

### Module Components

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Type</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO-502-A</td>
<td>Undergraduate Seminar Part I</td>
<td>Seminar</td>
<td>2.5</td>
</tr>
<tr>
<td>CO-502-B</td>
<td>Undergraduate Seminar Part II</td>
<td>Seminar</td>
<td>2.5</td>
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</table>

### Module Coordinator

<table>
<thead>
<tr>
<th>I. Gorbovickies</th>
<th>Program Affiliation</th>
<th>Mandatory Status</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mathematics</td>
<td>for Mathematics</td>
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</table>

### Entry Requirements

<table>
<thead>
<tr>
<th>Pre-requisites</th>
<th>Co-requisites</th>
<th>Knowledge, Abilities, or Skills</th>
<th>Frequency</th>
<th>Forms of Learning and Teaching</th>
</tr>
</thead>
<tbody>
<tr>
<td>☒ Linear Algebra</td>
<td>☒ None</td>
<td>None beyond formal prerequisites</td>
<td>annually</td>
<td>Seminar (35 hours) Private Study (90 hours)</td>
</tr>
</tbody>
</table>

### Duration

- 2 semesters
- 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 upon 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 this 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 databases for literature search
- 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
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.

Assessment

<table>
<thead>
<tr>
<th>Type: Presentation</th>
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<tbody>
<tr>
<td>Scope: All intended learning outcomes of this module</td>
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Additional bonus homework as a voluntary task can improve the grade by 0.33 points (German grading system) but is not required to reach the best grade in the module (1.0).
7.7 Introductory Algebra

<table>
<thead>
<tr>
<th>Module Name</th>
<th>Module Code</th>
<th>Level (type)</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Introductory Algebra</td>
<td>CO-503</td>
<td>Year 2 (CORE)</td>
<td>7.5</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Module Components</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>Name</td>
<td>Type</td>
</tr>
<tr>
<td></td>
<td>CO-503-A</td>
<td>Lecture</td>
</tr>
<tr>
<td></td>
<td>Introductory Algebra</td>
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</tr>
<tr>
<td></td>
<td>CO-503-B</td>
<td>Tutorial</td>
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<tr>
<td></td>
<td>Introductory Algebra Tutorial</td>
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</table>

<table>
<thead>
<tr>
<th>Module Coordinator</th>
<th>Program Affiliation</th>
<th>Mandatory Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Penkov</td>
<td>Mathematics</td>
<td>Mandatory for Mathematics</td>
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<table>
<thead>
<tr>
<th>Entry Requirements</th>
<th>Frequency</th>
<th>Forms of Learning and Teaching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-requisites</td>
<td>annually</td>
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</tr>
<tr>
<td>☒ Linear Algebra</td>
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<td>Lectures (35 hours)</td>
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<tr>
<td>Co-requisites</td>
<td>Knowledge, Abilities, or Skills</td>
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<td>Private Study (135 hours)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Duration</th>
<th>Workload</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 semester</td>
<td>187.5 hours</td>
</tr>
</tbody>
</table>

Recommendations for Preparation

Review material from Linear Algebra

Content and Educational Aims

This module is an introductory 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. In more details, the module covers basic constructions in group theory 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, simple), basic examples of rings (e.g. polynomial rings, integral domains), divisibility theory in commutative rings (principal ideal domains and unique factorisation domains). The module also includes a basic introduction to the theory of fields, including field extensions, 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.

**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.

**Assessment**

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

Scope: All intended learning outcomes of this module

Additional bonus homework as a voluntary task can improve the grade by 0.33 points (German grading system) but is not required to reach the best grade in the module (1.0).
### 7.8 Analysis III

<table>
<thead>
<tr>
<th>Module Name</th>
<th>Module Code</th>
<th>Level (type)</th>
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</thead>
<tbody>
<tr>
<td>Analysis III</td>
<td>CO-504</td>
<td>Year 2 (CORE)</td>
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</table>

**Module Components**

<table>
<thead>
<tr>
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<th>Name</th>
<th>Type</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO-504-A</td>
<td>Analysis III</td>
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<td>CO-504-B</td>
<td>Analysis III Tutorial</td>
<td>Tutorial</td>
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**Program Affiliation**
- Mathematics

**Mandatory Status**
- Mandatory for Mathematics

**Entry Requirements**

<table>
<thead>
<tr>
<th>Pre-requisites:</th>
<th>Co-requisites</th>
<th>Knowledge, Abilities, or Skills</th>
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</thead>
<tbody>
<tr>
<td>☒ Analysis I</td>
<td>☒ None</td>
<td>None beyond formal pre-requisites</td>
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<tr>
<td>☒ Applied Mathematics</td>
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</table>

**Frequency**
- annually

**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 upon 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 which provide a natural setting of many problems in nonlinear analysis, mathematical physics, and partial differential equations. 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 Lebesgue integral. Emphasis is put on the limit theorems (Fatou’s lemma, monotone convergence, 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 integration of differential forms will be provided and Stokes' Theorem, which is already known from 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 the Lebesgue integrals
- use the central limit theorems in a variety of contexts
- formulate and employ 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

### 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

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

Additional bonus homework as a voluntary task can improve the grade by 0.33 points (German grading system) but is not required to reach the best grade in the module (1.0).
## 7.9 Real Analysis

<table>
<thead>
<tr>
<th>Module Name</th>
<th>Module Code</th>
<th>Level (type)</th>
<th>CP</th>
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</thead>
<tbody>
<tr>
<td>Real Analysis</td>
<td>CA-S-MATH-801</td>
<td>2/3 (Specialization)</td>
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### Module Components

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA-MATH-801</td>
<td>Real Analysis</td>
<td>Lecture</td>
</tr>
</tbody>
</table>

### Module Coordinator

- **Program Affiliation**: Mathematics
- **Mandatory Status**: Mandatory elective for Mathematics

### Entry Requirements

- **Pre-requisites**:
  - Analysis I
  - Applied Mathematics
  - Linear Algebra

- **Co-requisites**: None
- **Knowledge, Abilities, or Skills**:
  - None beyond formal pre-requisites
- **Frequency**: Biennial

### Forms of Learning and Teaching

- Lectures (35 hours)
- Private Study (90 hours)

### Duration

- 1 semester
- 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, Hahn-Banach theorem, weak topologies, compactness theorems (Tychnov's theorem, Banach-Alaoglu theorem, Arzela-Ascoli theorem), Hilbert spaces, 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

### Usability and Relationship to other Modules

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

### Assessment

- **Type**: Written examination
- **Duration**: 120 min
- **Weight**: 100%

Scope: All intended learning outcomes of this module
Additional bonus homework as a voluntary task can improve the grade by 0.33 points (German grading system) but is not required to reach the best grade in the module (1.0).
7.10 Complex Analysis

Module Name
Complex Analysis

Module Code
CA-S-MATH-802

Level (type)
Year 2/3 (Specialization)

CP
5.0

Module Components

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Type</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA-MATH-802</td>
<td>Complex Analysis</td>
<td>Lecture</td>
<td>5.0</td>
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</tbody>
</table>

Module Coordinator
A. Huckleberry

Program Affiliation
• Mathematics

Mandatory Status
Mandatory elective for Mathematics

Entry Requirements

Pre-requisites
☒ Analysis I
☒ Calculus
☒ Elements of Linear Algebra II
☐ None

Co-requisites
☒ None

Knowledge, Abilities, or Skills
• None beyond formal pre-requisites

Frequency
biennial

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. 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 delicate 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 which 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 in 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

Usability and Relationship to other Modules
This module is a specialization module in Mathematics to be taken in Semester 3 or 5.

<table>
<thead>
<tr>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>Scope: All intended learning outcomes of this module</td>
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</table>

Additional bonus homework as a voluntary task can improve the grade by 0.33 points (German grading system) but is not required to reach the best grade in the module (1.0).
## 7.11 Stochastic Processes

<table>
<thead>
<tr>
<th><strong>Module Name</strong></th>
<th><strong>Module Code</strong></th>
<th><strong>Level (type)</strong></th>
<th><strong>CP</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Stochastic Processes</td>
<td>CA-S-MATH-803</td>
<td>Year 2/3 (Specialization)</td>
<td>5.0</td>
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### Module Components

<table>
<thead>
<tr>
<th><strong>Number</strong></th>
<th><strong>Name</strong></th>
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</thead>
<tbody>
<tr>
<td>CA-MATH-803</td>
<td>Stochastic Processes</td>
<td>Lecture</td>
<td>5.0</td>
</tr>
</tbody>
</table>

### Module Coordinator

- **K. Mallahi-Karai**
  - **Program Affiliation**
    - Mathematics

### Entry Requirements

- **Pre-requisites**
  - "Applied Mathematics" or "Probability and Random Processes"
  - No Co-requisites

- **Knowledge, Abilities, or Skills**
  - None beyond formal pre-requisites

### Frequency

- Biennial

### Forms of Learning and Teaching

- Lectures (35 hours)
- Private Study (90 hours)

### Duration

- 1 semester

### Workload

- 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 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, 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;
- analyse 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.

**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.

**Assessment**

<table>
<thead>
<tr>
<th>Type: Written examination</th>
<th>Duration: 120 min</th>
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<tr>
<td>Weight: 100%</td>
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</table>

Scope: All intended learning outcomes of this module

Additional bonus homework as a voluntary task can improve the grade by 0.33 points (German grading system) but is not required to reach the best grade in the module (1.0).
7.12 Numerical Analysis

<table>
<thead>
<tr>
<th>Module Name</th>
<th>Module Code</th>
<th>Level (type)</th>
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</thead>
<tbody>
<tr>
<td>Numerical Analysis</td>
<td>CA-S-MATH-804</td>
<td>2/3 (Specialization)</td>
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**Module Components**

<table>
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<th>Number</th>
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<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA-MATH-804</td>
<td>Numerical Analysis</td>
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</table>

**Module Coordinator**

T. Preusser

**Program Affiliation**

- Mathematics

**Mandatory Status**

Mandatory elective for Mathematics

**Entry Requirements**

<table>
<thead>
<tr>
<th>Pre-requisites</th>
<th>Co-requisites</th>
<th>Knowledge, Abilities, or Skills</th>
</tr>
</thead>
</table>
| ☐ Analysis I or Applied Mathematics | ☐ None | The following modules are recommended, but not required prior to taking this module:  
  - Numerical methods  
  - Applied Mathematics |

**Frequency**

biennially

**Forms of Learning and Teaching**

- Lectures (35 hours)
- Private Study (90 hours)

**Duration**

1 semester

**Workload**

125 hours

**Recommendations for Preparation**

- Revise your knowledge in Analysis and Linear Algebra

**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, consistency
- Equivalence theorem of Lax-Richtmeyer for exemplary problems
- Types of error analysis (forward, backward, a priori, a posteriori)
- Sources of errors (modeling, data, discretization, rounding and truncation)
- Foundations of matrix analysis: Vector norms and matrix norms, compatible/consistent norms
- Stability analysis for linear systems: condition number of a matrix, forward/backward a priori analysis, convergence of iterative methods
- Iterative methods: Gradient descent, conjugate gradient method
- Review of Lagrange interpolation, error estimates, drawbacks and Runge’s counterexample, stability of polynomial interpolation, piecewise Lagrange interpolation, extensions to the multi-dimensional case
- Quadrature formulas: interpolatory quadrature, error estimates, Gauss quadrature, degree of exactness, extensions to the multi-dimensional case
- Finite difference approximations, stability and convergence analysis for FDM, error estimates for FDM
- The notion of weak solution
- Ritz-Galerkin method and the Finite Element Method (FEM)
- Error estimates for FEM: Cea’s Lemma, approximation estimates
- Particular examples in 1D and 2D, 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

### 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.

### Assessment

<table>
<thead>
<tr>
<th>Type</th>
<th>Duration: 120 min</th>
<th>Weight: 100%</th>
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</thead>
<tbody>
<tr>
<td>Written examination</td>
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</table>

Scope: All intended learning outcomes of this module

Additional bonus homework as a voluntary task can improve the grade by 0.33 points (German grading system) but is not required to reach the best grade in the module (1.0).
7.13 Dynamical Systems

<table>
<thead>
<tr>
<th>Module Name</th>
<th>Module Code</th>
<th>Level (type)</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamical Systems</td>
<td>CA-S-MATH-805</td>
<td>Year 2/3 (Specialization)</td>
<td>5.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Module Components</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>Name</td>
<td>Type</td>
</tr>
<tr>
<td>CA-MATH-805</td>
<td>Dynamical Systems</td>
<td>Lecture</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Module Coordinator</th>
<th>Program Affiliation</th>
<th>Mandatory Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Gorbovickies</td>
<td>• Mathematics</td>
<td>Mandatory elective for Mathematics</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Entry Requirements</th>
<th>Frequency</th>
<th>Forms of Learning and Teaching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-requisites</td>
<td>biennial</td>
<td>• Lectures (35 hours)</td>
</tr>
<tr>
<td>“Analysis I” or “Applied Mathematics”</td>
<td></td>
<td>• Private Study (90 hours)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Knowledge, Abilities, or Skills</th>
<th>Duration</th>
<th>Workload</th>
</tr>
</thead>
<tbody>
<tr>
<td>• None beyond formal pre-requisites</td>
<td>1 semester</td>
<td>125 hours</td>
</tr>
</tbody>
</table>

**Recommendations for Preparation**

Review material from Analysis I and Applied Mathematics

**Content and Educational Aims**

This module is an introductory 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 study their properties.

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

- 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, 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.
- distinguish different forms of dynamical systems, qualitatively and quantitatively.

**Usability and Relationship to other Modules**

- This module is a specialization module in Mathematics to be taken in Semester 4 or 6.

**Assessment**

<table>
<thead>
<tr>
<th>Type: Written examination</th>
<th>Duration: 120 min</th>
<th>Weight: 100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scope: All intended learning outcomes of this module</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Additional bonus homework as a voluntary task can improve the grade by 0.33 points (German grading system) but is not required to reach the best grade in the module (1.0).
# 7.14 Foundations of Mathematical Physics

<table>
<thead>
<tr>
<th>Module Name</th>
<th>Module Code</th>
<th>Level (type)</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundations of Mathematical Physics</td>
<td>CA-S-MATH-806</td>
<td>Year 2/3 (Specialization)</td>
<td>5</td>
</tr>
</tbody>
</table>

## Module Components

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Type</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA-</td>
<td>Foundations of Mathematical Physics</td>
<td>Lecture</td>
<td>5</td>
</tr>
</tbody>
</table>

## Module Coordinator

- S. Petrat
- Program Affiliation: Mathematics
- Mandatory Status: Mandatory elective for Mathematics and Physics

## Entry Requirements

<table>
<thead>
<tr>
<th>Co-requisites</th>
<th>Knowledge, Abilities, or Skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>☒ None</td>
<td>Good command of linear algebra, analysis, and calculus</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequentiation</th>
<th>Forms of Learning and Teaching</th>
</tr>
</thead>
<tbody>
<tr>
<td>biennially</td>
<td>Lectures (35 hours) Private Study (90 hours)</td>
</tr>
</tbody>
</table>

## Duration

- 1 semester
- Workload: 125 hours

## Recommendations for Preparation

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

## Content and Educational Aims

This module is about the application of mathematics in physics. Physics and mathematics have a very intimate relationship. On the one hand, big discoveries in physics have often led to interesting new mathematics, and on the other hand, new developments in mathematics have made new discoveries in physics possible. The goal of this module is to look at some examples of that, and to get an insight into which role rigorous mathematics has played and plays nowadays 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

### 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

### Assessment
<table>
<thead>
<tr>
<th>Type: Written examination</th>
<th>Duration: 120 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scope: All intended learning outcomes of this module</td>
<td></td>
</tr>
</tbody>
</table>

Additional bonus homework as a voluntary task can improve the grade by 0.33 points (German grading system) but is not required to reach the best grade in the module (1.0).
Module Name: Partial Differential Equations

Module Code: CA-S-MATH-807
Level (type): Year 2 (Specialization)
CP: 5

Module Components

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Type</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA-MATH-807</td>
<td>Partial Differential Equations</td>
<td>Lecture</td>
<td>5</td>
</tr>
</tbody>
</table>

Module Coordinator: M. Oliver

Program Affiliation:
- Mathematics

Mandatory Status:
- Mandatory elective for Mathematics

Entry Requirements
Pre-requisites
- None
- Analysis I or Applied Mathematics

Co-requisites
- None

Knowledge, Abilities, or Skills
- It is strongly recommended that students take the module “Applied Mathematics” before taking this module

Frequency
- Biennially

Forms of Learning and Teaching
- Lectures (35 hours)
- Private Study (90 hours)

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, linear prototypes (transport equation, Poisson equation, heat equation, 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, introduction to conservation laws; exact solution techniques, transformation methods, power series solutions, asymptotics. To attend the class, students should have good command of analysis, some knowledge in real analysis is beneficial.

The following topics will be covered:
- Examples of PDEs
- Classification of PDEs
- Laplace’s equation & Poisson’s equation
- Dirichlet problem
- Mean value formulas
- Maximum principles, uniqueness of solutions
- Harmonic, sub-harmonic, super-harmonic functions
- Liouville’s theorem, Harnack’s inequality
- Fundamental solution, Green’s function
- Poisson’s integral formula
- Perron’s method, method of continuity
- Regularity of classical solutions
- Weak derivatives
- Approximation by smooth functions
- Weak solution
- Wave equation: D’Alembert’s formula, energy methods
- First order PDEs: method of characteristics
- Scalar conservation laws, Hamilton-Jacobi equations
- Legendre transform, Hopf-Lax formula

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

- demonstrate their mastering 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

**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

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

Scope: All intended learning outcomes of this module

Additional bonus homework as a voluntary task can improve the grade by 0.33 points (German grading system) but is not required to reach the best grade in the module (1.0).
## 7.16 Algebra

### Module Components

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Type</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA-MATH-808</td>
<td>Algebra</td>
<td>Lecture</td>
<td>5.0</td>
</tr>
</tbody>
</table>

### Entry Requirements

**Pre-requisites:** Introductory Algebra

**Co-requisites:** None

**Knowledge, Abilities, or Skills:** None beyond formal pre-requisites

### Forms of Learning and Teaching

- Lectures (35 hours)
- Private Study (90 hours)

### Frequency

Biennial

### Duration

1 semester

### Workload

125 hours

### 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.

### Intended Learning Outcomes

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

- demonstrate their mastering 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

### Usability and Relationship to other Modules

- This module is a specialization module in Mathematics to be taken in Semester 4 or 6.

### Assessment

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

Additional bonus homework as a voluntary task can improve the grade by 0.33 points (German grading system) but is not required to reach the best grade in the module (1.0).
## 7.17 Topology

### Module Name
Topology

### Module Code
CA-S-MATH-809

### Level (type)
Year 2 (Specialization)

### CP
5

### Module Components

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Type</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA-MATH-809</td>
<td>Topology</td>
<td>Lecture</td>
<td>5</td>
</tr>
</tbody>
</table>

### Module Coordinator
A. Huckleberry

### Program Affiliation
- Mathematics

### Mandatory Status
Mandatory elective for Mathematics

### Entry Requirements

#### Pre-requisites
- ☒ Calculus and Elements of Linear Algebra I and II
- ☒ Advanced Calculus
- ☒ None

#### Co-requisites
- Knowledge, Abilities, or Skills
  - Good command of linear algebra, analysis, and calculus

### Knowledge, Abilities, or Skills
- Good command of linear algebra, analysis, and calculus

### Frequency
Biennially

### 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
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 of 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 study of more advanced topics in algebraic topology

### 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

**Assessment**

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

Scope: All intended learning outcomes of this module

Additional bonus homework as a voluntary task can improve the grade by 0.33 points (German grading system) but is not required to reach the best grade in the module (1.0).
### 7.18 Applied Dynamical Systems Lab

<table>
<thead>
<tr>
<th><strong>Module Name</strong></th>
<th>Applied Dynamical Systems Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Module Code</strong></td>
<td>CA-S-MATH-810</td>
</tr>
<tr>
<td><strong>Level (type)</strong></td>
<td>Year 2/3 (Specialization)</td>
</tr>
<tr>
<td><strong>CP</strong></td>
<td>7.5</td>
</tr>
</tbody>
</table>

#### Module Components

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Type</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA-MATH-810</td>
<td>Applied Dynamical Systems Lab</td>
<td>Lecture with integrated Lab component</td>
<td>7.5</td>
</tr>
</tbody>
</table>

#### Module Coordinator

- **Program Affiliation**
  - Mathematics

- **Mandatory Status**
  - Mandatory elective for Mathematics

#### Entry Requirements

<table>
<thead>
<tr>
<th>Pre-requisites</th>
<th>Co-requisites</th>
<th>Knowledge, Abilities, or Skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>☒ Calculus and Elements of Linear Algebra II</td>
<td>☒ None</td>
<td>• Python programming as can be learned in the first-year module “Applied Mathematics” or any Programming in Python classica&lt;br&gt;• Advanced Multivariable Calculus as taught in the first-year module “Applied Mathematics” is helpful, but not required.&lt;br&gt;• Analysis I is helpful, but not required.</td>
</tr>
</tbody>
</table>

#### Frequency

- **Frequency**
  - bienniel

#### Forms of Learning and Teaching

- Class Sessions (51.5 hours)
- Private Study (135 hours)

#### Duration

- **Duration**
  - 1 semester

#### Workload

- **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 own laptop and know how to edit and start simply Python programs in a Python IDE like Spyder (which comes bundled as part of Anaconda Python).
### Content and Educational Aims

This module is a hands-on introduction to 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 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 algorithms 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 submission of code and reports

### 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.

### Assessment

Type: Project (portfolio)  
Scope: All intended learning outcomes of this module  

Additional bonus homework as a voluntary task can improve the grade by 0.33 points (German grading system) but is not required to reach the best grade in the module (1.0).
## 7.19 Stochastic Methods Lab

<table>
<thead>
<tr>
<th>Module Name</th>
<th>Module Code</th>
<th>Level (type)</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stochastic Methods Lab</td>
<td>CA-S-MATH-811</td>
<td>2/3 (Specialization)</td>
<td>7.5</td>
</tr>
</tbody>
</table>

### Module Components

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Type</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA-MATH-811</td>
<td>Stochastic Methods Lab</td>
<td>Lecture with integrated Lab component</td>
<td>7.5</td>
</tr>
</tbody>
</table>

### Module Coordinator

- **Program Affiliation**
  - Mathematics

### Mandatory Status

- Mandatory elective for Mathematics and IMS

### Entry Requirements

- **Pre-requisites**
  - Calculus and Linear Algebra I and 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 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.

### Frequency

- Biennial

### Forms of Learning and Teaching

- Class Sessions (52.5 hours)
- Private Study (135 hours)

### Duration

- 1 semester

### 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 own laptop and know how to edit and start simply Python programs in a Python IDE like Spyder (which comes bundled as part of Anaconda Python).

### Content and Educational Aims

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

Topics include a short introduction to the basic notions of financial mathematics, binomial tree models, discrete Brownian paths, stochastic integrals and ODEs, Ito’s Lemma, Monte-Carlo methods, finite differences solutions, the Black-Scholes equation, and an introduction to time series analysis, parameter estimation, and calibration. Students will program and explore all basic techniques in a numerical programming environment and apply these algorithms to real data whenever possible.
### Intended Learning Outcomes
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 submission of code and reports

### 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.

### Assessment

**Type:** Project (portfolio)  
**Weight:** 100%

**Scope:** All intended learning outcomes of this module

Additional bonus homework as a voluntary task can improve the grade by 0.33 points (German grading system) but is not required to reach the best grade in the module (1.0).
7.20 Algebraic Topology

Module Components

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Type</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA-MATH-812</td>
<td>Algebraic Topology</td>
<td>Lecture</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Module Coordinator

I. Penkov

Program Affiliation

- Mathematics

Mandatory Status

Elective for Mathematics

Entry Requirements

Pre-requisites

☑ Introductory Algebra

Co-requisites

☑None

Knowledge, Abilities, or Skills

- None beyond formal pre-requisites

Frequency

Biennial

Forms of Learning and Teaching

- Lectures (35 hours)
- Private Study (90 hours)

Duration

1 semester

Workload

125 hours

Recommended for Preparation

Review material from Introductory Algebra

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. Then further algebraic concepts such as cohomology and the multiplicative structure in cohomology are introduced. In the last section the duality between homology and cohomology of manifolds is studied and few basic elements of obstruction theory are discussed.

The module gives a solid introduction to fundamental ideas and results that are used nowadays in most areas of pure mathematics and theoretical physics.

Intended Learning Outcomes

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

- demonstrate their mastering 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

Usability and Relationship to other Modules

- This module is a specialization module in Mathematics to be taken in Semester 4 or 6.

Assessment

Type: Written Exam
Duration: 120 min
Scope: All intended learning outcomes of this module

Weight: 100%
Additional bonus homework as a voluntary task can improve the grade by 0.33 points (German grading system) but is not required to reach the best grade in the module (1.0).
7.21 Internship / Startup and Career Skills

<table>
<thead>
<tr>
<th>Module Name</th>
<th>Module Code</th>
<th>Level (type)</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internship / Startup and Career</td>
<td>CA-INT-900</td>
<td>Year 3 (CAREER)</td>
<td>15</td>
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</table>

**Module Components**

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Type</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA-INT-900-0</td>
<td>Internship</td>
<td>Internship</td>
<td>15</td>
</tr>
</tbody>
</table>

**Module Coordinator**
- Predrag Tapavicki & Christin Klähn (CSC Organization); SPC/Startup Coordinator (Academic responsibility);

**Program Affiliation**
- CAREER module for undergraduate study programs

**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**
- Information provided on CSC pages (see below)
- Major specific knowledge and skills

**Frequency**
- Annually

**Forms of Learning and Teaching**
- Internship/Start-up
- Internship Event
- Seminars, Info-sessions, Workshops and Career Events
- Self-Study, Readings, Online Tutorials

**Duration**
- 1 semester

**Workload**
- 375 Hours consisting of:
  - Internship (308 hours)
  - Workshops (33 hours)
  - Internship Event (2 hours)
  - Self-study (32 hours)

**Recommendations for Preparation**
- Reading the information in the menu sections “Internship Information”, “Career Events”, “Create Your Application” and “Seminars & Workshops” at the Career Services Center website [http://csc-microsite.user.jacobs-university.de/](http://csc-microsite.user.jacobs-university.de/)
- Completing all four online tutorials about the job market preparation and the application process ([http://csc-microsite.user.jacobs-university.de/create-your-application/tutorials/](http://csc-microsite.user.jacobs-university.de/create-your-application/tutorials/))
- Participation at Internship Events of earlier classes

**Content and Educational Aims**

The aims of the internship module are reflection, application, orientation and development: For students to reflect on their interests, knowledge, skills, their role in society, the relevance of their major subject in society, to apply these skills and this knowledge in real life whilst getting practical experience, to find professional orientation, and develop their personality and in their career. The 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 major area of study and extends over a minimum period 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 times, such as before teaching starts in the 3rd 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.

The internship will be gradually prepared in semesters 1 to 4 by 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 job interviews and/or assessment centers. In addition to this mandatory part, students can customize their set of skills regarding the application challenges and 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 the acquired job market skills in an actual internship/job search situation and to gain a 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 initial StartUp-idea. This presentation will be held at the beginning of the 4th semester. A jury of faculty members will judge the potential to realize the 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 set out in the Policies for Bachelor Studies apply.

The concluding Internship Event will be conducted in each study program (or a cluster of related study programs) and will formally conclude the module by providing students the opportunity to present their internships and reflect on the lessons learned within their major area of study. The purpose is not only to self-reflect the whole process but also to create the professional network within the academic community, especially with the aspect of entering the Alumni Network after graduation. It is recommended that all three classes of the same major are present at this event to enable the creation of networks between older and younger students and to create a learning environment for younger students in the sense of “lessons learned” effect from 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: identify personal interests, select appropriate internship destinations or start-up opportunities, conduct interviews, pitches or assessment centers, negotiate related employment, 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 expectations by and consequences for employers and the society;
- reflect on and set own targets for further development of their knowledge, skills, interests and values;
- establish and expand contacts with potential employers or business partner and possibly other students and alumni to build their own professional network to create employment opportunities in the future;
- discuss observations and reflection in a professional network.

**Usability and Relationship to other Modules**

- Mandatory for a major in BCCB, Chemistry, 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.

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<thead>
<tr>
<th>Assessment</th>
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<tbody>
<tr>
<td>Type: Internship Report or Business Plan and Reflection</td>
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<td>Scope: All intended learning outcomes</td>
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### 7.22 Bachelor Thesis and Seminar

<table>
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<th>Module Name</th>
<th>Module Code</th>
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<tr>
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#### Module Components

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<td>CA-MATH-800-S</td>
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#### Module Coordinator

- **Study Program Chair**: All undergraduate programs

#### Program Affiliation

- All undergraduate programs

#### Mandatory Status

Mandatory for all undergraduate programs

#### Entry Requirements

**Pre-requisites**

- Students must be in the third year and have taken at least 30 CP from CORE modules of their major.
- No Co-requisites

**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.

**Frequency**

- Annually

**Forms of Learning and Teaching**

- Self-study/lab work (350 hours)
- Seminars (25 hours)

**Duration**

- 1 semester

**Workload**

- 375 hours

#### 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 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.
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.

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.

Type: Presentation
Duration: approx. 15 to 30 minutes
Weight: 20%

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

Two separate assessments are justified by the size of the 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 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 Linear Algebra I

<table>
<thead>
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<th>Module Name</th>
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<td>JTMS-09</td>
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<tbody>
<tr>
<td>Marcel Oliver, Tobias Preußer</td>
<td>Jacobs Track – Methods and Skills</td>
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#### Mandatory Status

Mandatory for CS, ECE, IMS, MATH and Physics
Mandatory elective for EES

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<tbody>
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<td>125 hours</td>
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</tr>
</thead>
<tbody>
<tr>
<td>1 semester</td>
<td>125 hours</td>
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</table>
vector, polar coordinates)

- Some familiarity in 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 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 lies in 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 done 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
- Derivative
- 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.

### 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 and mathematician.
- Mandatory for a major in CS, ECE, IMS, MATH and Physics
- Mandatory elective for a major in EES.
- Pre-requisite for Calculus and Linear Algebra II
- Elective for all other study programs.

**Assessment**

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Scope: All intended learning outcomes of this module
### 7.23.1.2 Calculus and Linear Algebra II

<table>
<thead>
<tr>
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<th>Module Code</th>
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<tr>
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<tr>
<td>Marcel Oliver, Tobias Preußer</td>
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<td>Mandatory for CS, ECE, MATH, Physics, IMS</td>
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<table>
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<tr>
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<td>Lectures (35 hours)</td>
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<table>
<thead>
<tr>
<th>Duration</th>
<th>Workload</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 semester</td>
<td>125 hours</td>
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</table>

### Recommendations for Preparation

Review the content of Calculus and Elements of Linear Algebra I

### Content and Educational Aims

This module is the second in a sequence introducing mathematical methods at 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 lies in 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 done 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 theorem, 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.

### 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 done 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
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<tr>
<th>Type: Written examination</th>
<th>Duration: 120 min</th>
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</table>
Scope: All intended learning outcomes of this module
# 7.23.1.3 Probability and Random Processes

## Module Name
Probability and Random Processes

## Module Code
JTMS-MAT-12

## Level (type)
- Year 2 (Methods)
- CP: 5

## Module Components

### Number
JTMS-12

### Name
Probability and random processes

### Type
Lecture

### CP
5

## Module Coordinator
Marcel Oliver, Tobias Preußer

### Program Affiliation
- Jacobs Track – Methods and Skills

## Entry Requirements

### Pre-requisites
- Calculus and 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 one and several variables, trigonometric functions, logarithm and exponential function).
- 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.

## Frequency
Annually

## Forms of Learning and Teaching
- Lectures (35 hours)
- Private Study (90 hours)

## 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 at providing 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 & Sample Space. Combinatorial probability.
- Conditional probability and Bayes’ formula.
- Binomials & 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 & Moments, Covariance.
- High dimensional probability: Chebyshev and Chernoff bounds.
- Moment Generating Functions & Characteristic Functions,
- The Central limit theorem.
- Random Vectors & 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.

**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, 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

<table>
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<th><strong>Module Code</strong></th>
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<th>Year 2 (Methods)</th>
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<th>Year 2 (Methods)</th>
<th><strong>CP</strong></th>
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<td>Jacobs Track – Methods and Skills</td>
<td>Mandatory for ECE, MATH, Physics Mandatory elective for CS and IMS</td>
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<th><strong>Knowledge, Abilities, or Skills</strong></th>
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<td>☒ None</td>
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<td>Workload</td>
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<td></td>
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<td>125 hours</td>
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<table>
<thead>
<tr>
<th><strong>Recommendations for Preparation</strong></th>
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</thead>
</table>
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 which are 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 potential limitations and caveats of such algorithms.

**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.
- 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).
- 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**

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<tr>
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</table>

Scope: All intended learning outcomes of this module
7.23.2 Big Questions Modules

7.23.2.1 Digitalization: Challenges and Opportunities for Business and Society

<table>
<thead>
<tr>
<th>Module Name</th>
<th>Module Code</th>
<th>Level (type)</th>
<th>CP</th>
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<tbody>
<tr>
<td>Big Questions: Digitalization: Challenges and Opportunities for Business and Society</td>
<td>JTBQ-BQ-001</td>
<td>Year 3 (Jacobs Track)</td>
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</table>

**Module Components**

<table>
<thead>
<tr>
<th>Number</th>
<th>Type</th>
<th>CP</th>
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</thead>
<tbody>
<tr>
<td>JTBQ-001</td>
<td>Digitalization: challenges and opportunities for business and society</td>
<td>Lecture/Projects</td>
</tr>
</tbody>
</table>

**Module Coordinator**

A. Wilhelm

**Program Affiliation**

- Jacobs Track - Big Questions

**Mandatory Status**

- Mandatory elective for students of all undergraduate study programs except IEM

**Entry Requirements**

<table>
<thead>
<tr>
<th>Pre-requisites</th>
<th>Co-requisites</th>
<th>Knowledge, Abilities, or Skills</th>
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<tr>
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<td>• the ability and openness to engage in interdisciplinary issues of global relevance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• media literacy, critical thinking and a proficient handling of data sources</td>
</tr>
</tbody>
</table>

**Frequency**

Annually

**Forms of Learning and Teaching**

- 17.5 h Lectures
- 90 h Project work
- 17.5 h Private Study

**Duration**

1 semester

**Workload**

125 hours

**Recommendations for Preparation**

Critical following of 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 support students in their development to become an informed and responsible citizen in a global society.

Digitalization is currently one of the major change drivers in our globalized world affecting all aspects of our lives: from private aspects, such as the way we find and select friends and partners, to economic principles such as the replacement of human labor by robots and artificial intelligence. Big data is a further buzz word of the digitalization process: the massive storage and analysis of comprehensive information of customers and citizens instill both hopes and fears to the public. From a business perspective, digitalization is often portrayed as a sea of big opportunities while at the same time many companies are under pressure to comply and adapt to rapidly changing processes and business approaches. The public debate on digitalization, particularly on big data, is torn between the two poles portrayed by the writers George Orwell and Aldous Huxley: complete surveillance and oppression on the one end, irrelevance and narcissism on the other. The technological research quite naturally is mostly concerned with the technical feasibility of the approaches, the
continuously increasing challenges with respect to the digitalization process, and the creative solutions needed to tackle them. In this module, you will get an overview on digitalization by looking at it from various aspects, primarily the business and societal point of view. There will be a fundamental exposition to the technological side of digitalization as far as it is needed for assessing the societal and business implications.

**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 debate about big data, the pros and cons, from both a business perspective as well as a societal perspective
- prioritize the major threats and opportunities of digitalization
- advance a knowledge-based opinion on how technological possibilities and innovations can drive business practices and initiate public discourse and debate
- complete a self-designed project, collect information, distill information and summarize in a suitable reporting format
- overcome general teamwork problems in order to perform well-organized project work

**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: Team project  Weight: 100%

Scope: All intended learning outcomes of the module
7.23.2.2 Water: The Most Precious Substance on Earth

<table>
<thead>
<tr>
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<th>Level (type)</th>
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<tr>
<td>Big Questions: Water: The Most Precious Substance on Earth</td>
<td>JTBQ-BQ-002</td>
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### Module Components

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<tr>
<td>JTBQ-002</td>
<td>Water - The most precious substance on earth</td>
<td>Lecture/Tutorial</td>
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#### Program Affiliation
- Jacobs Track - Big Questions

#### 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

### Forms of Learning and Teaching
- 17.5 h Lectures
- 90h Project work
- 17.5 Private Study

### Duration
- 2 semesters

### Workload
- 125 hours

### Recommendations for Preparation

Critical following of 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 support students in their development to become an informed and responsible citizen in a global society.

Water is the basic prerequisite for life on our planet, but has become a scarce resource and a valuable commodity; it is of fundamental importance for the world economy and for global food supply and 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, as well as from social and cultural sciences.

Following topical lectures in the Fall semester, students will work on projects on the occasion of World Water Day (March 22) in small teams comprised of students from various disciplines and with different cultural backgrounds. The teamwork will be accompanied by related tutorials.

### Intended Learning Outcomes

Students acquire transferable and key skills in this module.

By the end of this module, students will be able to
1. use their disciplinary factual and methodological knowledge to reflect on interdisciplinary questions by comparing approaches from various disciplines
2. advance a knowledge-based opinion on the complex module topics: on the physico-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 the cultural values and meanings of water.
3. formulate coherent written and oral contributions (e.g., to (panel) discussions) on the topic
4. perform well-operating teamwork
5. present a self-designed project in a university-wide context

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: Intended learning outcomes (1-3) | Weight: 50% |

| Type: Team project | Weight: 50% |
| Scope: Intended learning outcomes (1-5) |
# 7.23.2.3 Ethics in Science and Technology

<table>
<thead>
<tr>
<th>Module Name</th>
<th>Module Code</th>
<th>Level (type)</th>
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<tbody>
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<td>Big Questions: Ethics in Science and Technology</td>
<td>JTBQ-BQ-003</td>
<td>Year 3 (Jacobs Track)</td>
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## Module Components

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<tr>
<td>JTBQ-003</td>
<td>Ethics in Science and Technology</td>
<td>Lecture /Projects</td>
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</table>

### Module Coordinator

- A. Lerchl

#### Program Affiliation

- Jacobs Track - Big Questions

#### Mandatory Status

- Mandatory for Chemistry
- Mandatory elective for all other 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

## Forms of Learning and Teaching

- 35 h Lectures (hours)
- 55 h Project work
- 35 h Private Study

## Duration

- 1 semester

## Workload

- 125 hours

## Recommendations for Preparation

Critical following of 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. 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.

Ethics is an often neglected, but essential part of science and technology. Our decisions about right and wrong influenced the way, how our inventions and developments change the world. A wide array of examples will be presented and discussed, e.g., foundation of ethics, individual vs. population ethics, artificial life, stem cells, animal rights, abortion, pre-implantation diagnostics, legal and illegal drugs, 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

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

**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.
- Mandatory for a major in Chemistry

**Assessment**

Type: Written examination  
Duration: 60 min  
Weight: 50%

Scope: Intended learning outcomes (1-9)

Type: team project  
Weight: 50%

Scope: Intended learning outcomes (1, 3-12)
# 7.23.2.4 Global Health – Historical context and future challenges

<table>
<thead>
<tr>
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<th>Module Code</th>
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<td>Big Questions: Global Health – Historical context and future challenges</td>
<td>JTBQ-BQ-004</td>
<td>Year 3 (Jacobs Track)</td>
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## Module Components

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<tbody>
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<td>JTBQ-004</td>
<td>Global Health – Historical context and future challenges</td>
<td>Lecture</td>
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## Module Coordinator

A. M. Lisewski

### Program Affiliation

- Jacobs Track - Big Questions

### Mandatory Status

- Mandatory elective for students of all undergraduate study programs except IEM

## Entry Requirements

<table>
<thead>
<tr>
<th>Pre-requisites</th>
<th>Co-requisites</th>
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</tr>
<tr>
<td></td>
<td></td>
<td>• media literacy, critical thinking and a proficient handling of data sources</td>
</tr>
</tbody>
</table>

## Frequency

Annually

## Forms of Learning and Teaching

- Lectures (35 hours)
- Private Study (90 hours)

## 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 support students in their development to become an informed and responsible citizen in a global society.

This module gives a historical, societal, technical, scientific and medical overview over the past and future milestones and challenges of global health. Particular focus is on future global health issues in a world that is interconnected both through mobility and through communication networks. Presented are 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 economy. Focus is given to children, maternal and adolescent health, as these are most critical to the well-being of next generations. The module also provides key concepts in global health, epidemiology and demographics such as the connection between a society’s economical level and its population’s health status, measures of health status, demographic and epidemiologic transitions, as well as modern issues such as the growing fragmentation (to a personal level) of disease conditions and the resulting emergence of personalized medicine. Finally, attention is also given to publicly less prominent global health issues, such as re-emergent 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 today's global health surveillance and response systems and institutions;
- discuss and evaluate the imminent and future challenges of public hygiene and response to disease outbreaks in a global society network context.

### 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

<table>
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Scope: All intended learning outcomes of the module
7.23.2.5 Global Existential Risks

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<tbody>
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<td>Big Questions: Global Existential Risks</td>
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Module Components

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<tr>
<td>JTBQ-005</td>
<td>Global Existential Risks</td>
<td>Lecture</td>
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Module Coordinator

M. A. Lisewski

Program Affiliation

- Jacobs Track - Big Questions

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

Forms of Learning and Teaching

- Lectures (17.5 hours)
- Private Study (45 hours)

Duration

1 semester

Workload

62.5 hours

Recommendations for Preparation

Critical following of 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 support students in their development to become an informed and responsible citizen in a global society.

The more we develop science and technology, the more we also learn about global catastrophic and, in the worst case, even absolutely existential dangers that put the entire human civilization at risk to total collapse and thus to an abrupt and irrevocable end. These doomsday risks 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 lecture presents the main known varieties of existential risks including, for example, astrophysical, planetary, biological, and technological events and critical transitions that have a capacity to severely damage or even to eradicate Earth-based human civilization as we know it. It further offers a description of their characteristic features, 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, it reviews some hypothetical monitoring and early warning systems as well as analysis methods that could potentially be used in strategies, if not to eliminate, but at least to better understand and ideally to minimize imminent global existential risks. This interdisciplinary lecture will allow students to look 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 disciplinary 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 the risks;
- formulate coherent written and oral contributions on the topic.

## 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

<table>
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Scope: All intended learning outcomes of the module
### 7.23.2.6 Future - From Predictions and Visions to Preparations and Actions

<table>
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<td>Big Questions: Future: From Predictions and Visions to Preparations and Actions</td>
<td>JTBQ-BQ-006</td>
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#### Module Components

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<td>JTBQ-006</td>
<td>Future: From Predictions and Visions to Preparations and Actions</td>
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#### Module Coordinator

Joachim Vogt

#### Program Affiliation

- Jacobs Track - Big Questions

#### Mandatory Status

- Mandatory elective for students of all undergraduate study programs except IEM

#### Entry Requirements

<table>
<thead>
<tr>
<th>Pre-requisites</th>
<th>Co-requisites</th>
<th>Knowledge, Abilities, or Skills</th>
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<td></td>
<td></td>
<td>• media literacy, critical thinking and a proficient handling of data sources</td>
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</tbody>
</table>

#### Frequency

- annually

#### Forms of Learning and Teaching

- Lecture (17.5 hours)
- Private Study (45 hours)

#### Duration

- 1 semester

#### Workload

- 62.5 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 support students in their development to become an informed and responsible citizen in a global society.

This module addresses selected topics related to Future as a general concept in science, technology, culture, literature, ecology, economy, and consists of three parts. The first part (Future Continuous) discusses forecasting methodologies rooted in the idea that the 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 chances and challenges for present and future generations.
### 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
- distinguish and qualify important approaches to forecasting and prediction
- summarize the history of utopias and dystopias, and ideas presented in classical science fiction
- characterize current developments in technology, ecology, society, and their implications for the future

### 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

<table>
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Scope: All intended learning outcomes of the module
# 7.23.2.7 Climate Change

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<td>Big Questions: Climate Change</td>
<td>JTBQ-BQ-007</td>
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## Module Components

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<td>JTBQ-007</td>
<td>Climate Change</td>
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</table>

## Module Coordinator

L. Thomsen/V. Unnithan

### Program Affiliation

- Jacobs Track - Big Questions

### Mandatory Status

- Mandatory elective for students of all undergraduate study programs except IEM

## Entry Requirements

- **Pre-requisites**: None
- **Co-requisites**: None

<table>
<thead>
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<th>Knowledge, Abilities, or Skills</th>
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</tr>
<tr>
<td>media literacy, critical thinking and a proficient handling of data sources</td>
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</tbody>
</table>

## Frequency

- **annually**

## Forms of Learning and Teaching

- **Lecture (17.5 hours)**
- **Private Study (45 hours)**

## Duration

- **1 semester**

## Workload

- **62.5 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 support students in their development to become an informed and responsible citizen 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 to modern times and will focus on geological, cosogenic 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, onset of early life, snowball Earth, and modern glaciation cycles. In the second part, the course will focus on 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 of climate mitigation (geo-engineering) and adaptation of our society to climate change (such as coastal protection and adoption 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, the 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: impacts of climate change on the natural environment over geological timescales and since the industrial revolution, 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.

**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
### Module Name
**Big Questions: Extreme Natural Hazards, Disaster Risks and Societal Impact**

<table>
<thead>
<tr>
<th>Module Code</th>
<th>Level (type)</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>JTBQ-BQ-008</td>
<td>Year 3 (Jacobs Track)</td>
<td>2.5</td>
</tr>
</tbody>
</table>

### Module Components

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Type</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>JTBQ-008</td>
<td>Extreme Natural Hazards: Disaster Risks and Societal Impact</td>
<td>Lecture</td>
<td>2.5</td>
</tr>
</tbody>
</table>

### Module Coordinator
L. Thomsen

### Program Affiliation
- Jacobs Track - Big Questions

### Mandatory Status
- Mandatory elective for students of all undergraduate study programs except IEM

### Entry Requirements

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

### Frequency

daily

### Forms of Learning and Teaching
- Lecture (17.5 hours)
- Private Study (45 hours)

### Duration
1 semester

### Workload
62.5 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 support students in their development to become an informed and responsible citizen in a global society.

Extreme natural events, increasingly dominate our global headlines, and understanding their causes, risks, and impacts, as well as the costs of 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 such as volcanoes, earthquakes, landslides, hurricanes, precipitation floods and space weather, and provides real-world hazard case studies from Latin America, the Caribbean, Africa, the Middle East, Asia and the Pacific region.

### 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;
- advance a knowledge-based opinion on the complex module topics: how earth processes affect and interact with our civilization, especially those that create hazards;
- distinguish the methods scientists use to predict and assess the risk of natural hazards,
- discuss the social implications and policy framework in which decisions are made to manage natural disasters,
- work effectively in a team environment.

### 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
7.23.2.9 International Development Policy

<table>
<thead>
<tr>
<th>Module Name</th>
<th>Module Code</th>
<th>Level (type)</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big Questions: International Development Policy</td>
<td>JTBQ-BQ-009</td>
<td>Year 3 (Jacobs Track)</td>
<td>2.5</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Module Components</th>
<th>Number</th>
<th>Name</th>
<th>Type</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>JTBQ-009</td>
<td>International Development Policy</td>
<td>Lecture</td>
<td>2.5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Module Coordinator</th>
<th>Program Affiliation</th>
<th>Mandatory Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>C. Knoop</td>
<td>• Jacobs Track - Big Questions</td>
<td>• Mandatory elective for students of all undergraduate study programs except IEM</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Entry Requirements</th>
<th>Frequency</th>
<th>Forms of Learning and Teaching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-requisites: None</td>
<td>annually</td>
<td>• Lecture (17.5 hours)</td>
</tr>
<tr>
<td>Co-requisites: None</td>
<td></td>
<td>• Oral Presentations</td>
</tr>
<tr>
<td>Knowledge, Abilities, or Skills</td>
<td></td>
<td>• Private Study (45 hours)</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Duration</th>
<th>Workload</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 semester</td>
<td>62.5 hours</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Recommendations for Preparation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical following of the media coverage on the module’s topics in question.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Content and Educational Aims</th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
</tr>
</tbody>
</table>

We live in a world where still a large number of people live in absolute poverty and without access to basic needs and services, such as food, sanitation, health care, security and proper education. This module provides an introduction to 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 learn about the tools applied in modern development policies but also about critical aspects of monitoring and evaluating the results of development policy. Module related oral presentations and debates will enhance the students’ learning experience.
### 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.

### 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

<table>
<thead>
<tr>
<th>Type: Presentation</th>
<th>Duration: 10 minutes per student</th>
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<tbody>
<tr>
<td>Weight: 100%</td>
<td></td>
</tr>
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</table>

Scope: All intended learning outcomes of the module
# Module 7.23.2.10 Global Challenges to International Peace and Security

<table>
<thead>
<tr>
<th><strong>Module Name</strong></th>
<th><strong>Module Code</strong></th>
<th><strong>Level (type)</strong></th>
<th><strong>CP</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Big Questions: Global Challenges to International Peace and Security</td>
<td>JTBQ-BQ-010</td>
<td>Year 3 (Jacobs Track)</td>
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<table>
<thead>
<tr>
<th><strong>Module Components</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number</strong></td>
</tr>
<tr>
<td>JTBQ-010</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Module Coordinator</strong></th>
<th><strong>Program Affiliation</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>C. Knoop</td>
<td>Jacobs Track - Big Questions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Entry Requirements</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre-requisites</strong></td>
</tr>
<tr>
<td>☒ None</td>
</tr>
<tr>
<td></td>
</tr>
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</table>

<table>
<thead>
<tr>
<th><strong>Frequency</strong></th>
<th><strong>Forms of Learning and Teaching</strong></th>
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<td>annually</td>
<td>Lecture (35h)</td>
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<tr>
<td></td>
<td>Private Study (90h)</td>
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<table>
<thead>
<tr>
<th><strong>Duration</strong></th>
<th><strong>Workload</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 semester</td>
<td>125 hours</td>
</tr>
</tbody>
</table>

**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 support students in their development to become an informed and responsible citizen in a global society.

We live in a multi-polar world where multiple crisis situations have rather become the rule than the exception. World peace and security are challenged by various developments and factors, such as the risk of proliferation of weapons of mass destruction, the spread of international terrorism, organized and cybercrime but also by the man-made and natural effects of climate changes and the growing gap between the few very rich and the many utterly poor people living on our planet. This module provides an introduction to some of the most important threat scenarios for global peace and security. The students will learn about the tools available to deal with these challenges with a focus on the European Union, the African Union and the United Nations. In this context, the concepts of multilateralism and bilateral efforts to achieve world peace and security will also be examined.
**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 global threats to peace and security;
- identify, explain and evaluate important tools available to international actors in the interest of world peace and security;
- formulate well-justified criticism of these tools and explain their limits;
- summarize and present a module related topic in an appropriate verbal and visual form;

**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: Presentation
Duration: 10 minutes
Weight: 100%

Scope: All intended learning outcomes of the module
## Module Name
Sustainable Value Creation with Biotechnology. From Science to Business.

<table>
<thead>
<tr>
<th>Module Code</th>
<th>Level (type)</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>JTBQ-BQ-011</td>
<td>Year 3 (Jacobs Track)</td>
<td>2.5</td>
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### Module Components

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Type</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>JTBQ-011</td>
<td>Biotechnology: From Science to Business</td>
<td>Lecture - Tutorial</td>
<td>2.5</td>
</tr>
</tbody>
</table>

### Module Coordinator
Marcelo Fernandez Lahore

### Program Affiliation
- Jacobs Track - Big Questions

### Mandatory Status
- Mandatory for Chemistry
- 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

### 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://www.ctsi.ucla.edu/researcher-resources/files/view/docs/EGBS4_Kolchinsky.pdf)
- [https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf](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 from 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 course. 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 course 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.

## 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

<table>
<thead>
<tr>
<th>Type</th>
<th>Length/Duration</th>
<th>Scope</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Term Paper</td>
<td>1.500 – 3.000 words</td>
<td>Intended learning outcomes of the module (1-6)</td>
<td>75%</td>
</tr>
<tr>
<td>Presentation</td>
<td>10-15 min.</td>
<td>Intended learning outcomes of the module (2-7)</td>
<td>25%</td>
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</table>

Weight: 75%
## 7.23.3 Community Impact Project

<table>
<thead>
<tr>
<th>Module Name</th>
<th>Community Impact Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module Code</td>
<td>JTCI-CI-950</td>
</tr>
<tr>
<td>Level (type)</td>
<td>Year 3 (Jacobs Track)</td>
</tr>
<tr>
<td>CP</td>
<td>5</td>
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### Module Components

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Type</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>JTCI-950</td>
<td>Community Impact Project</td>
<td>Project</td>
<td>5</td>
</tr>
</tbody>
</table>

### Module Coordinator

- CIP Faculty Coordinator

### Program Affiliation

- Jacobs Track - Community Impact Project

### Mandatory Status

Mandatory for all undergraduate study programs except IEM

### Entry Requirements

**Pre-requisites**
- ☒ see below

**Co-requisites**
- None

**Knowledge, Abilities, or Skills**
- Basic knowledge of the main concepts and methodological instruments of the respective disciplines
- xxxxx

**Frequency**

- annually

### 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, 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 the students’ acquired knowledge and skills. The activities will ideally be connected to their majors, so that they will challenge the students’ sense of practical relevance and social responsibility within the field of their studies. Projects will tackle real issues in their direct and/or broader social environment. They ideally connect the campus community to other communities, companies, 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 by the CIP faculty coordinator team and faculty mentors in doing 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 support and guidance by faculty and the CIP faculty coordinator team.

### Intended Learning Outcomes

The Community Impact Project is designed to convey the required personal and social competencies to enable students to finish their studies at Jacobs as socially conscious and responsible graduates (Jacobs mission) and to convey social and personal competencies to the students, including a practical awareness for the societal context and relevance of their academic discipline:

- understand real life issues of communities, organizations and industries and relate them to concepts of the own discipline;
- enhance problem-solving skills and develop critical faculty, create solutions to problems and communicate them appropriately to their audience;
- apply media and communication skills in diverse and non-peer social contexts;
- develop awareness for the societal relevance of own scientific action and a sense of social;
- responsibility for the social surrounding;
- reflect own behaviour critically in relation to social expectations and consequences;
- ability to work in a team and deal with diversity, develop cooperation and conflict skills, strengthen empathy and ambiguity tolerance.

**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 generations’ 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
## 8.1 Intended Learning Outcomes Assessment-Matrix

<table>
<thead>
<tr>
<th>Mathematics B.Sc</th>
<th>Assessment</th>
<th>Competencies*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>E</td>
</tr>
<tr>
<td>Semester</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Credits</td>
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<td>7.5</td>
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<td>m</td>
</tr>
<tr>
<td>mandatory elective</td>
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<td>m</td>
</tr>
<tr>
<td>Intended Learning Outcomes</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Program Learning Outcomes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mathematically rigorous arguments and understanding the concept of mathematical proofs</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Recognize patterns and discover underlying principles</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Confidence in the application of methods in the core fields of pure and applied mathematics (Analysis, Linear Algebra, Numerical Analysis, Probability, Topology, Geometry)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Independently perform simple proofs and derivations in these fields and the principles behind more complicated proofs and derivations</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>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</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Write simple programs in at least one programming language</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Have basic knowledge about standard mathematical software packages and use them productively in everyday problem solving</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Formulate mathematical ideas in written text</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Present mathematical ideas to others</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Think analytically</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Present complex ideas to specialists and non-specialists</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Are confident in acquiring, understanding, and organizing information</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>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 work effectively in a diverse team and to take responsibility in a team</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Demonstrate a sense for the use of Mathematics in one or more fields of application</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Engage ethically with academic and professional communities, and with the general public to actively contribute to a sustainable future, reflecting and respecting different views</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Take responsibility for their own learning, personal and professional development and role in society, evaluating critical feedback and self-analysis</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Take on responsibility in a diverse team and adhere to and defend ethical, scientific and professional standards</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Assessment Type</strong></td>
<td></td>
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<tr>
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<td>x</td>
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<tr>
<td>Final written exam</td>
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<tr>
<td>Project portfolio</td>
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<tr>
<td>Lab report</td>
<td>x</td>
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<tr>
<td>Poster presentation</td>
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<tr>
<td>Thesis</td>
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<tr>
<td>Module achievements/bonus achievements</td>
<td>x</td>
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</tbody>
</table>

*Competencies: A-scientific/academic proficiency; E-competence for qualified