EBERHARD KARLS UNIVERSITÄT TÜBINGEN

Mathematisch-Naturwissenschaftliche Fakultät

Department of Mathematics

Module Handbook

Mathematik

Master of Education Erweiterungsfach

Lehramt Gymnasium*

Summer Semester 2026

Last updated on 13th April 2026

*This is a secondary school teaching degree with a major in mathematics. The module handbook is valid for the 2019 study and examination regulations.

Contents

1 Desciption of the Study Programme

1.1 Qualification Objectives

As part of the teaching-related Master's study programme Master of Education Erweiterungsfach Lehramt Gymnasium with mathematics as a subject graduates acquire fundamental and in-depth subject-specific and subject-didactic knowledge and competences, as required necessary for science-based teaching at secondary schools. These enable them to organise targeted teaching, learning and educational processes in the subject of mathematics and to introduce new subject-specific and interdisciplinary developments into teaching and school development independently.

Graduates are familiar with the fundamental problems in linear algebra, analysis, numerical mathematics, stochastics, geometry and algebra and have mastered the central techniques for solving them. They acquire basic mathematical thinking patterns such as structuring problems, creating chains of reasoning and finally proving mathematical theorems. Graduates are able to communicate mathematical facts, use suitable media and establish links to school mathematics. Building on the fundamental issues mentioned above, they expand their material and methodological skills in a compulsory elective area from the specialisations offerd in Tübingen: Algebra and Geometry, Analysis and Differential Geometry, Mathematical Physics, Numerical Mathematics and Optimisation or Stochastics. Graduates are proficient in the theoretical approaches, principles and methods of mathematics. They are able to provide examples of the current state of research and can critically scrutinise it. Graduates can use their in-depth knowledge to develop and solve their own simple research ideas. They can derive, analyse, prove and interpret specific questions from general mathematical concepts. Graduates are able to present, explain and discuss the results of their research work in depth in front of a scientific audience, both in writing and orally.

Students combine their scientific knowledge with didactic methods, use suitable media and are able to use theoretical concepts and empirical findings from mathematics-related teaching-learning research to analyse thought processes and ideas of pupils in exercises and to guide individual learning processes. They know and evaluate the concepts for learning and teaching mathematics at school on the basis of subject-didactic theories and empirical findings. They are able to analyse, plan and exemplarily implement mathematics lessons with heterogeneous learning groups on the basis of subject-didactic concepts. Students can justify the educational value of mathematical content, convey the societal significance of mathematics and place it in the context of the objectives and content of mathematics lessons.

1.2 Structure of the Study Programme

The study of the extension subject in the teacher training programme is usually taken up in parallel to the study of the two main subjects. This requires individual counselling for each and every student with regard to the structure and design of their study programme. At the beginning of their studies, all students on this study programme should therefore seek academic advice from the Faculty Course Advisor in the Department of Mathematics and discuss with them an individual study plan that takes into account the student's previous knowledge and special circumstances. In the module handbook, we can only describe the structure and organisation of the degree programme for the rather atypical case that the degree programme is completed full-time and not in parallel with another degree programme.

The first year of study is dominated by the large compulsory module Foundations of Mathematics and the module Consolidation of the Foundations of Mathematics, in which the subject-specific basics of analysis and linear algebra from an academic point of view are conveyed. The corresponding lectures are accompanied by exercise classes, where students are intensively supervised and taught basic mathematical thinking and working methods as well as the ability to present solutions. In addition, the department provides students with revision sessions as question times.

In the second, third and, in some cases, fourth semesters, the students deepen their theoretical knowledge. They expand their knowledge in the areas of algebra, geometry, numerical mathematics and stochastics and attend a introductory seminar. The content of the compulsory modules is taught in lectures and accompanying exercise classes. Each lecture is accompanied by weekly tasks that students have to complete in writing. In the exercise classes, the students present their solutions or create them under supervision. Through this system, which is common in mathematics study programmes, it is intended to teach students to systematically work on the tasks set for them and to practise analytical and structural thinking. Furthermore, they should be able to present complex mathematical facts in writing and orally. This requires students to be able to organise themselves and to do a lot of independent study which is expected and recognised in the course of study. At the same time, intensive supervision and individualised support options are provided. In the third and fourth semesters, students also gain their first insights into specialisation areas through a compulsory elective lecture and a seminar. The focus of the final semester is the Master's thesis.

In addition to the specialised modules, students take modules in the field of subject didactics from the second semester onwards. The Subject Didactics 1 and 2 modules are designed in such a way that for the didactic courses in the areas of stochastics and geometry it is recommended to take them parallel with the corresponding subject modules. In the subject modules, the subject-specific prerequisites for the subject didactics courses are taught. Different focal points can then be set in the Subject Didactics 3 module, although one part of the module has a strong professional focus.

It is not possible to specify a specific time frame for a study period at a foreign university when studying an extension subject, as experience has shown that the study structure is too individual and different. This can only be planned in a personal consultation with the Faculty Course Advisor. Essentially, from the perspective of mathematics every semester is eligible for this. The decision will depend on the student's previous achievements and the programme offered at the chosen foreign university.

2 Study Plans

2.1 Overview by Modules

Here we provide an overview of the study plan as a table showing the modules to be taken.

ST	Module Number	Module Title	Type of Course	Type of Module	Course-work	Type of Exam	ECTS-Points
Section 1: Foundations of Mathematics							
1+2	MAT-10-10	Foundations of Mathematics		PM		or.	27
		- Linear Algebra 1	L+E+T		EC		
		- Analysis 1	L+E+T		EC		
		- Analysis 2	L+E+T		EC		
1-3	MAT-10-11	Consolidation of the Foundations of Mathematics		PM		wr. o. or.	6
		- Algebraic Structures	L+E		EC		
		- Mathematical Software	P		PC		
Section 2: Compulsory Intermediate Modules							
3-4	MAT-20-02	Introduction to Complex Analysis and Ordinary Differential Equations	L+E	PM	EC	wr. o. or.	9
2-3	MAT-20-03	Algebra	L+E	PM	EC	wr. o. or.	9
2-3	MAT-20-11	Numerical Mathematics	L+E	PM	EC	wr. o. or.	9
2-3	MAT-20-12	Stochastics	L+E	PM	EC	wr. o. or.	9
2-3	MAT-50-01	Geometry	L+E	PM	EC	wr. o. or.	9
2-4	MAT-20-20	Introductory Seminar: Presentations in Mathematics	PS	PMW	s.M.	Pr	3
Section 3: Knowledge Expansion Mathematics							
3-4	MAT-40-51	Specialisation	L+E	PMW	EC	wr. o. or.	9
Section 4: Didactics of Mathematics							
2-3	MAT-80-01	Subject Didactics Mathematics 1	LIC	PM	s.M.	K o. mP o. P	3
2-3	MAT-80-02	Subject Didactics Mathematics 2	SLIC+SLIC	PM	-	K o. mP o. R o. H o. P.	6
3-4	MAT-80-03	Subject Didactics Mathematics 3	S+SV	PMW	-	K o. mP o. R o. H	6

Section 5: Master Thesis							
4	MAT-40-53	Master Thesis	MT	PM	s.M.	MT	15

Abbreviations:
- Type of Module : PM=compulsory module, PMW=compulsory module with choice, WPM=elective module
- Examination Type : MT=master's thesis, or.=oral exam, wr.=written exam, Pr=presentation, E=essay, P=portfolio, T=continous assessment tests
- Teaching Format : L=lecture, LE=lecture with integrated exercises, SL=seminar or lecture, E=exercise class, T=revision course, P=practical course, PS=introductory seminar, S=seminar, IC=inverted classroom
- Course Work : EC=exercise certificate, PEC=practical exercise certificate, PC=practical certificate
- Other : h=hours, o.=or, s.M.=see module description, ST=suggested term

Note at the request of the student representatives on the Study Commission: For modules extending over several semesters, it is strongly recommended to review the content of each submodule thoroughly during the lecture-free periods, thereby spreading the preparation for the oral examination over a longer period of time.

2.2 Overview by the Course of Studies

All students on this study programme should attend a study counselling session with the Faculty Course Advisor at the Department of Mathematics at the beginning of their studies to discuss an individual study plan that takes into account the student's previous knowledge and the particular circumstances of the respective student. This applies especially if the degree programme is taken up parallel to the study of the two first subjects. Here we provide an overview of the possible course of study in the form of a table both for entry in the winter semester and for entry in the summer semester in the case of regular full-time study.

<table>
<tr><th colspan="8">Possible Study Plan for Students Starting in the Winter Semester</th></tr>
<tr><th>FS</th><th>CP</th><th colspan="6">Module Achievements</th></tr>
<tr><td>1</td><td>21</td><td colspan="2" rowspan="2">Foundations of Mathematics
(27 CP)</td><td colspan="4">Consolidation of the Foundations of Mathematics
(6 CP)</td></tr>
<tr><td>2</td><td>36</td><td>Algebra
(9 CP)</td><td>Stochastics
(9 CP)</td><td rowspan="2">Subject Didactics Mathematics 2
(6 CP)</td><td>Subject Didactics Mathematics 1
(3 CP)</td></tr>
<tr><td>3</td><td>36</td><td>Specialisation
(9 CP)</td><td>Introductory seminar
(3 CP)</td><td>Geometry
(9 CP)</td><td>Numerical Mathematics
(9 CP)</td><td rowspan="2">Subject Didactics Mathematics 3
(6 CP)</td></tr>
<tr><td>4</td><td>27</td><td>Introduction to Complex Analysis and Ordinary Differential Equations
(9 CP)</td><td colspan="4">Master Thesis
(15 CP)</td></tr>
<tr><td colspan="8">Explanation of the Abbreviations:
FS=semester, CP=credit points (ECTS points)</td></tr>
</table>

<table>
<tr><th colspan="8">Possible Study Plan for Students Starting in the Summer Semester</th></tr>
<tr><th>FS</th><th>CP</th><th colspan="6">Module Achievements</th></tr>
<tr><td>1</td><td>21</td><td colspan="2" rowspan="2">Foundations of Mathematics
(27 CP)</td><td colspan="4">Consolidation of the Foundation of Mathematics
(6 CP)</td></tr>
<tr><td>2</td><td>36</td><td>Geometry
(9 CP)</td><td>Numerical Mathematics
(9 CP)</td><td rowspan="2">Subject Didactics Mathematics 2
(6 CP)</td><td>Introductory seminar
(3 CP)</td></tr>
<tr><td>3</td><td>36</td><td>Introduction to Complex Analysis and Ordinary Differential Equations
(9 CP)</td><td>Subject Didactics Mathematics 1
(3 CP)</td><td>Algebra
(9 CP)</td><td>Stochastics
(9 CP)</td><td rowspan="2">Subject Didactics Mathematics 3
(6 CP)</td></tr>
<tr><td>4</td><td>27</td><td>Specialisation
(9 CP)</td><td colspan="4">Master Thesis
(15 CP)</td></tr>
<tr><td colspan="8">Explanation of the Abbreviations:
FS=semester, CP=credit points (ECTS points)</td></tr>
</table>

2.3 Overview of Programme Structure with Semester Assignment

Overview of Programme Structure with Semester Assignment for Students Starting in the Winter Semester

		Exam				Teaching				Semester			
		Type of Exam	Duration (min)	Grading	Weight in the final grade	Type of Course	Status	SWS	ECTS Points(CP)	The allocation of examinations / ECTS points to semesters is of a recommendatory nature. The allocation of ECTS points to courses are of an informative nature. Credits are only awarded upon completion of the module.			
										1. CP	2. CP	3. CP	4. CP
Section 1: Foundations of Mathematics									**33**				
Foundations of Mathematics								24	27				
1.	Lecture					L	o	12		9	9		
2.	Exercise class	Or.	20-30	g	27	E	o	6		6	3		
3.	Revision course					R	o	6		0	0		
Consolidation of the Foundations of Mathematics								4	6				
1.	Lecture	Wr. o. Or.	90-180 o. 20-30	g	6	L	o	2		3			
2.	Exercise class					E	o	1		1,5			
3.	Practical course	-		ng		P	o	1		1,5			
Section 2: Compulsory Intermediate Modules									**48**				
Stochastics								6	9				
1.	Lecture	Wr. o. Or.	90-180 o. 20-30	g	9	L	o	4			6		
2.	Exercise class					E	o	2			3		
Algebra								6	9				
1.	Lecture	Wr. o. Or.	90-180 o. 20-30	g	9	L	o	4			6		
2.	Exercise class					E	o	2			3		
Numerical Mathematics								6	9				
1.	Lecture	Wr. o. Or.	90-180 o. 20-30	g	9	L	o	4				6	
2.	Exercise class					E	o	2				3	
Geometry								6	9				
1.	Lecture	Wr. o. Or.	90-180 o. 20-30	g	9	L	o	4				6	
2.	Exercise class					E	o	2				3	
Introductory seminar Presentations in Mathematics								2	3				
1.	Introductory seminar	Pres		g	3	PS	o	2				3	
Introduction to Complex Analysis and Ordinary Differential Equations								6	9				
1.	Lecture	Wr. o. Or.	90-180 o. 20-30	g	9	L	o	4					6
2.	Exercise class					E	o	2					3

Overview of Programme Structure with Semester Assignment for Students Starting in the Winter Semester													
		Exam				Teaching				Semester			
		Type of Exam	Duration (min)	Grading	Weight in the final grade	Type of Course	Status	SWS	ECTS Points(CP)	The allocation of examinations / ECTS points to semesters is of a recommendatory nature. The allocation of ECTS points to courses are of an informative nature. Credits are only awarded upon completion of the module.			
										1. CP	2. CP	3. CP	4. CP
Section 3: Knowledge Expansion Mathematics									**9**				
Specialisation								6	9				
1.	Lecture	Wr. o. Or.	90-180 o. 20-30	g	9	L	o	4				6	
2.	Exercise class					E	o	2				3	
Section 4: Subject Didactics Mathematics									**15**				
Subject Didactics Mathematics 1								2	3				
1.	Subject Didactics 1	Wr. o. Or.	90-180 o. 20-30	g	3	SL	o	2			3		
Subject Didactics Mathematics 2								4	6				
1.	Subject Didactics 2 – Part 1	Wr. o. Or. o. Pres o. TP	90-180 o. 20-30	g	3	SL	o	2			3		
2.	Subject Didactics 2 – Part 2	Wr. o. Or. o. Pres o. TP	90-180 o. 20-30	g	3	SL	o	2				3	
Subject Didactics Mathematics 3								4	6				
1.	Seminar	Wr. o. Or. o. Pres o. TP	90-180 o. 20-30	g	3	S	o	2				3	
2.	Seminar / Lecture	Wr. o. Or. o. Pres o. TP	90-180 o. 20-30	g	3	SL	o	2					3
Section 4: Master Thesis									**15**				
Master Thesis									15				
1.	Master Thesis	MA		g		MA	o						15

Explanation of the Abbreviations:

Marking system : g=graded, ng=non graded
Form of examination : MA=master thesis, Or.=oral exam, Wr.=written exam, Pres=presentation, TP=term paper
Form of teaching : L=lecture, SL=Seminar or lecture, E=exercise class, r=revision course, P=practical course, PS=introductory seminar, S=seminar
Status : o=obligatory, f=facultative
Other : o.=or, SWS=hours in class per week, CP=credit points=ECTS Points

Overview of Programme Structure with Semester Assignment for Students Starting in the Summer Semester													
		Exam				Teaching				Semester			
		Type of Exam	Duration (min)	Grading	Weight in the final grade	Type of Course	Status	SWS	ECTS Points(CP)	The allocation of examinations / ECTS points to semesters is of a recommendatory nature. The allocation of ECTS points to courses are of an informative nature. Credits are only awarded upon completion of the module.			
										1. CP	2. CP	3. CP	4. CP
Section 1: Foundations of Mathematics									**33**				
Foundations of Mathematics								24	27				
1.	Lecture	Or.	20-30	g	27	L	o	12		9	9		
2.	Exercise class					E	o	6		6	3		
3.	Revision course					R	o	6		0	0		
Consolidation of the Foundations of Mathematics								4	6				
1.	Lecture	Wr. o. Or.	90-180 o. 20-30	g	6	L	o	2		3			
2.	Exercise class					E	o	1		1,5			
3.	Practical course	-		ng		P	o	1		1,5			
Section 2: Compulsory Intermediate Modules									**48**				
Numerical Mathematics								6	9				
1.	Lecture	Wr. o. Or.	90-180 o. 20-30	g	9	L	o	4			6		
2.	Exercise class					E	o	2			3		
Geometry								6	9				
1.	Lecture	Wr. o. Or.	90-180 o. 20-30	g	9	L	o	4			6		
2.	Exercise class					E	o	2			3		
Introductory seminar Presentations in Mathematics								2	3				
1.	Introductory seminar	Pres		g	3	PS	o	2			3		
Stochastics								6	9				
1.	Lecture	Wr. o. Or.	90-180 o. 20-30	g	9	L	o	4				6	
2.	Exercise class					E	o	2				3	
Algebra								6	9				
1.	Lecture	Wr. o. Or.	90-180 o. 20-30	g	9	L	o	4				6	
2.	Exercise class					E	o	2				3	
Introduction to Complex Analysis and Ordinary Differential Equations								6	9				
1.	Lecture	Wr. o. Or.	90-180 o. 20-30	g	9	L	o	4				6	
2.	Exercise class					E	o	2				3	

Overview of Programme Structure with Semester Assignment for Students Starting in the Summer Semester													
		Exam				**Teaching**				**Semester**			
		Type of Exam	Duration (min)	Grading	Weight in the final grade	Type of Course	Status	SWS	ECTS Points(CP)	The allocation of examinations / ECTS points to semesters is of a recommendatory nature. The allocation of ECTS points to courses are of an informative nature. Credits are only awarded upon completion of the module.			
										1. CP	2. CP	3. CP	4. CP
Section 3: Knowledge Expansion Mathematics									**9**				
Specialisation								6	9				
1.	Lecture	Wr. o. Or.	90-180 o. 20-30	g	9	L	o	4					6
2.	Exercise class					E	o	2					3
Section 4: Subject Didactics Mathematics									**15**				
Subject Didactics Mathematics 1								2	3				
1.	Subject Didactics 1	Wr. o. Or.	90-180 o. 20-30	g	3	SL	o	2				3	
Subject Didactics Mathematics 2								4	6				
1.	Subject Didactics 2 – Part 1	Wr. o. Or. o. Pres o. TP	90-180 o. 20-30	g	3	SL	o	2			3		
2.	Subject Didactics 2 – Part 2	Wr. o. Or. o. Pres o. TP	90-180 o. 20-30	g	3	SL	o	2				3	
Subject Didactics Mathematics 3								4	6				
1.	Seminar / Lecture	Wr. o. Or. o. Pres o. TP	90-180 o. 20-30	g	3	S	o	2				3	
2.	Seminar	Wr. o. Or. o. Pres o. TP	90-180 o. 20-30	g	3	SL	o	2					3
Section 4: Master Thesis									**15**				
Master Thesis									15				
1.	Master Thesis	MA		g		MA	o						15

Explanation of the Abbreviations:

Marking system : g=graded, ng=non graded
Form of examination : MA=master thesis, Or.=oral exam, Wr.=written exam, Pres=presentation, TP=term paper
Form of teaching : L=lecture, SL=Seminar or lecture, E=exercise class, r=revision course, P=practical course, PS=introductory seminar, S=seminar
Status : o=obligatory, f=facultative
Other : o.=or, SWS=hours in class per week, CP=credit points=ECTS Points

3 Module Descriptions

Section 1: Foundations of Mathematics

<table>
<tr><td>Module Number:
MAT-10-10</td><td colspan="2">Module Title:
Foundations of Mathematics</td><td>Type of Module:
Compulsory Module</td></tr>
<tr><td>ECTS-Points</td><td colspan="3">27</td></tr>
<tr><td>Workload
- Time in Class
- Self-Study</td><td>Workload:
810 h</td><td>Time in Class:
270 h</td><td>Self-Study:
540 h</td></tr>
<tr><td>Duration</td><td colspan="3">2 Semester</td></tr>
<tr><td>Frequency</td><td colspan="3">every Semester</td></tr>
<tr><td>Term</td><td colspan="3">1+2</td></tr>
<tr><td>Language of Instruction</td><td colspan="3">German</td></tr>
<tr><td>Forms of Teaching and Learning</td><td colspan="3">1. Semester: Linear Algebra 1, Lecture 4 SWS + Ex.cl. 2 SWS + Rev.c. 2 SWS
1. Semester: Analysis 1, Lecture 4 SWS + Ex.cl. 2 SWS + Rev.c. 2 SWS
2. Semester: Analysis 2, Lecture 4 SWS + Ex.cl. 2 SWS + Rev.c. 2 SWS</td></tr>
<tr><td>Higher Objectives</td><td colspan="3">In the Foundations of Mathematics module, students learn the essential conceptual and methodological foundations of linear algebra as well as single-variable and multivariable calculus, exploring their interconnections with particular emphasis on the similarities and differences in their approaches. In the oral exam, students demonstrate that they have recognised these relationships and are capable of contextualising the core results of the lectures within these frameworks.
The duration of the module supports these objectives while also accounting for the acquisition of a new language - the language of mathematics - and the development of a precise and rigorously logical working methodology. This provides students with the necessary time to make the significant transition from school-level mathematics to university-level mathematics. By demonstrating a deeper and more integrated understanding in the oral exams, students establish a strong foundation for successful participation in all subsequent modules in their academic programme.</td></tr>
</table>

Content	• Basic logic and sets. • Structure of real and complex numbers. • Sequences, convergence and series; criteria for convergence; power series, sequences of functions; pointwise and uniform covergence. • Continous functions in one dimension and between metric spaces and their properties. • One- and multidimensional differential calculus (especially: intermediate value theorem, Taylor expansion, implicit function theorem, inverse function theorem, extrema under constraints). • One- and multidimensional Riemann integral (especially Fubini's theorem, transformation formula). • Basic concepts of topology in metric and normed spaces. • Basic concepts of the theory of ordinary differential equations (Picard-Lindelöf theorem, linear ordinary differential equations, flows). • Vector spaces and linear maps. • Matrices and systems of linear equations. • Determinants, eigenvalues and diagonalisability. • Jordan canonical form. • Euclidean and unitary vector spaces, spectral theorems. • Basics of analytical geometry. • The lecture Analysis 1 focuses predominately on contents from one-dimensional analysis, the lecture Analysis 2 on multidimensional analysis. The lecture Linear Algebra 1 covers the contents of linear algebra.
Objectives	The students are familiar with and understand the fundamental concepts, statements, and methods of single-variable and multivariable calculus as well as linear algebra. They have also developed a foundational awareness of ordinary differential equations and initial value problems. Their capacity for abstraction has been enhanced, they have been trained in analytical thinking, and their mathematical imagination has been stimulated. Through a proof- and structure-oriented approach, they have learned to comprehend mathematical proofs in calculus and linear algebra and to independently prove or disprove mathematical statements in simple examples. They have recognised the essential relationships within the theory of single-variable and multivariable calculus, their similarities and differences, as well as their connections to linear algebra, and are able to contextualise the core results of the lectures within these frameworks. In the exercises, they have developed a confident, precise, and independent approach to the concepts, statements, and methods covered in the lectures. Additionally, their presentation and communication skills have been cultivated through written assignments and presenting their own solutions. The students are capable of acquiring knowledge through self-study, while their teamwork abilities have been fostered through collaboration in small groups.

Requirements for obtaining Credits / Grading (Weighting if applicable)

Title	Type of Course	Status	SWS	ECTS	Coursework	Type of Exam	Dur. of Exam (min)	Grading	Weight for Grade
Linear Algebra 1	L	o	4	6	yes	or.	30-40	g	100
	E	o	2	3					
	T	o	2	0					
Analysis 1	L	o	4	6	yes				
	E	o	2	3					
	T	o	2	0					
Analysis 2	L	o	4	6	yes				
	E	o	2	3					
	T	o	2	0					

In each of the three parts of the module an exercise certificate is to be acquired as coursework. The exercise certificate is acquired after regular participation in the exercise classes by taking part in a written test. Both partial assessments must be completed in the same semester.

The examination of the module consists of an oral exam covering all three parts of the module. To be eligible for the oral exam, students must have obtained at least one of the two exercise certificates for the Analysis 1 and Analysis 2 module parts, as well as the exercise certificate for the Linear Algebra 1 module part. The module is considered complete only when all three exercise certificates have been obtained and the oral exam has been successfully passed.
Of the 27 credit points for the module, 15 are allocated to the first semester and 12 to the second semester. The relatively higher share of credit points in the second semester, compared to the actual teaching hours, is due to the preparation required for the oral exam, which takes place after the second semester.

Literature

Possible References :

- Anton Deitmar: Analysis. Springer 2016.
- Otto Forster: Analysis 1. Springer Spektrum 2013.
- Otto Forster: Analysis 2. Vieweg+Teubner 2011.
- Theodor Bröcker: Lineare Algebra und analytische Geometrie. Birkhäuser 2013.
- Gerd Fischer: Lineare Algebra. Springer Spektrum 2014.

Transfer

The successful participation in the module Foundations of Mathematics is a prerequisite for the participation in all modules of Section 3 extension of knowledge mathematics and for the module Master Thesis. The exercise certificates of the module are prerequisite for all modules of the study programme but the module Consolidation of the Foundations of Mathematics.

Prerequisites

There are no prerequisites for participation in the module.

Responsible Persons

Victor Batyrev, Anton Deitmar, Christian Hainzl, Jürgen Hausen, Frank Loose, Hannah Markwig, Thomas Markwig, Reiner Schätzle, Stefan Teufel

Abbreviations:

Grading System	: g=graded, ng=not graded
Examination Type	: MT=master's thesis, or.=oral exam, wr.=written exam, Pr=presentation, E=essay, P=portfolio, T=continous assessment tests
Teaching Format	: L=lecture, LE=lecture with integrated exercises, SL=seminar or lecture, E=exercise class, T=revision course, P=practical course, PS=introductory seminar, S=seminar, IC=inverted classroom
Status	: o=obligatory, f=facultative
Other	: h=hours, o.=or, s.M.=see module description, SWS=contact hours per week

Module Number: MAT-10-11	**Module Title:** Consolidation of the Foundations of Mathematics		**Type of Module:** Compulsory Module
ECTS-Points	6		
Workload **- Time in Class** **- Self-Study**	Workload: 180 h	Time in Class: 60 h	Self-Study: 120 h
Duration	1 Semester		
Frequency	every Semester		
Term	1-3		
Language of Instruction	German		
Forms of Teaching and Learning	• Algebraic Structures, Lecture 2 SWS + Ex.cl. 1 SWS • Mathematical Software, Practical course 1 SWS		
Comment	The coursework and the examination in the module part algebraic structures can be replaced by the module Linear Algebra from the study programme Bachelor of Science Mathematics. The Mathematical Software sub-module is usually provided to students in the Bachelor of Education Lehramt Gymnasium by participating in the practical exercises in the module Numerical Mathematics. Further courses which could be taken instead will be listed in the course catalogue.		
Content	• Algebraic structures: – Groups, subgroups, group homomorphisms, normal subgroups, quotient group. – Cyclic groups and the symmetric group. – Commutative rings with one, divisibility. – Euclidean rings, principal ideal domains, factorial rings. – The ring of integers and the polynomial ring. • Mathematical software: – Getting to know one or more subject-specific software packages. – Implementation of simple algorithms, e.g. of linear algebra, in subject-typical software.		
Objectives	Students have learnt and understood essential aspects of linear algebra based on the Foundations of Mathematics module: the algebraic structures group and ring, which are essential for all areas of mathematics. They have deepened their structural skills acquired in the Foundations of Mathematics module. They are familiar with the most fundamental statements and methods in the field. Their capacity for abstraction has been enhanced, they have been trained in analytical thinking and their mathematical imagination has been stimulated. Using a proof- and structure-orientated approach, they have learnt to understand mathematical proofs of algebra and to independently prove or disprove mathematical statements using simple examples. They are able to place the structures they have learnt in linear algebra in a larger context and understand them better. In the exercise classes they have acquired a confident, precise and independent handling of the terms, statements and methods of the lecture. In addition, the students' presentation and communication skills were trained through written work and presenting their own solutions. The students are able to acquire knowledge through self-study and at the same time their ability to work in a team has been promoted by working in smaller groups. In the practical course on mathematical software, students have familiarised themselves with one or more subject-specific software packages or computer algebra systems. They are trained to work out selected problems, e.g. linear algebra, algorithmically and to implement the developed algorithms in a subject-specific software package. In doing so, they have expanded and deepened the algorithmic skills they acquired in the Foundations of Mathematics.		

<table>
<tr><td rowspan="5">Requirements for obtaining Credits / Grading (Weighting if applicable)</td><td>Title</td><td>Type of Course</td><td>Status</td><td>SWS</td><td>ECTS</td><td>Coursework</td><td>Type of Exam</td><td>Dur. of Exam (min)</td><td>Grading</td><td>Weight for Grade</td></tr>
<tr><td rowspan="2">Algebraic Structures</td><td>L</td><td>o</td><td>2</td><td>3</td><td rowspan="2">yes</td><td rowspan="2">wr. o. or.</td><td rowspan="2">90-180 o. 20-30</td><td rowspan="2">g</td><td rowspan="2">100</td></tr>
<tr><td>E</td><td>o</td><td>1</td><td>1,5</td></tr>
<tr><td>Mathematical Software</td><td>P</td><td>o</td><td>1</td><td>1,5</td><td>yes</td><td>-</td><td>-</td><td>nb</td><td>0</td></tr>
<tr><td colspan="10">In the sub-module Algebraic Structures an exercise certificate is to be acquired as coursework. For participation in the examination the coursework must have been acquired. Whether the examination is written or oral is decided by the instructor with approval by the head of the examination board.</td></tr>
<tr><td>Literature</td><td colspan="10">Possible References :
• Serge Lang: Algebraische Strukturen. Vandenhoek & Ruprecht 1979.
• Gerd Fischer: Lineare Algebra und Analytische Geometrie. Springer 2010.</td></tr>
<tr><td>Transfer</td><td colspan="10">The module is a prerequisite for all modules in the Section Knowledge Expansion Mathematics and for the module Master’s Thesis.</td></tr>
<tr><td>Prerequisites</td><td colspan="10">There are no prerequisites.</td></tr>
<tr><td>Responsible Persons</td><td colspan="10">Jürgen Hausen, Hannah Markwig, Thomas Markwig, Walther Paravicini</td></tr>
</table>

Abbreviations:

Grading System	: g=graded, ng=not graded
Examination Type	: MT=master’s thesis, or.=oral exam, wr.=written exam, Pr=presentation, E=essay, P=portfolio, T=continous assessment tests
Teaching Format	: L=lecture, LE=lecture with integrated exercises, SL=seminar or lecture, E=exercise class, T=revision course, P=practical course, PS=introductory seminar, S=seminar, IC=inverted class-room
Status	: o=obligatory, f=facultative
Other	: h=hours, o.=or, s.M.=see module description, SWS=contact hours per week

Section 2: Compulsory Intermediate Modules

Module Number: **MAT-20-02**	**Module Title:** Introduction to Complex Analysis and Ordinary Differential Equations		**Type of Module:** Compulsory Module
ECTS-Points	9		
Workload **- Time in Class** **- Self-Study**	Workload: 270 h	Time in Class: 90 h	Self-Study: 180 h
Duration	1 Semester		
Frequency	regularly in Summer Semester		
Term	3-4		
Language of Instruction	German		
Forms of Teaching and Learning	Lecture 4 SWS + Ex.cl. 2 SWS		
Content	• Complex Analysis: – Holomorphic functions, Cauchy-Riemann equations. – Antiderivatives, Cauchy's integral formula, Cauchy's integral theorem. – Compact convergence of families of functions, formal and convergent power series, complex-analytical functions, identity theorem. – Liouville's theorem, inverse function theorem for holomorphic functions, open mapping theorem, maximum principle. – Laurent series, holomorphic functions with isolated singularities, Casorati-Weierstrass theorem. – Residue theorem and applications. • Ordinary differential equations, a choice of the following: – Picard-Lindelöf existence and uniqueness theorem. – Linear ordinary differential equations, Gronwall's lemma. – Continous dependence on initial conditions, differential dependence on initial conditions. – Basics of dynamical systems, stability of equilibrium positions, characteristic exponents, first integrals, Liapunov-functions. – Ordinary differential equations over the complex numbers. – Regularity, the criterion of Fuchs. – The method of Frobenius.		
Objectives	The students know the foundations of the theory of complex analysis and ordinary differential equations. The are acquainted to essential calculation techniques and can calculate line integrals as well as explicitly solve simple differential equations. They know fundamental applications of the theory like e.g. the fundamental theorem of algebra and the Newtonian equations of motion. They also have the ability to transfer abstract questions into concrete problems of complex analysis or respectively of ordinary differential equations and solve them this way. In the exercise classes they have acquired a confident, precise and independent handling of the terms, statements and methods of the lecture. Furthermore the presentation and communication skills of the students was trained by written assignments and presenting their own solutions. The students are capable of adopting knowledge by self-study and at the same time their capacity for teamwork was enhanced by working in small groups.		

Requirements for obtaining Credits / Grading (Weighting if applicable)

Title	Type of Course	Status	SWS	ECTS	Coursework	Type of Exam	Dur. of Exam (min)	Grading	Weight for Grade
Introduction to Complex Analysis and ODEs.	L	o	4	6	yes	wr. o. or.	90-180 o. 20-30	g	100
	E	o	2	3					

In this module an exercise certificate is to be acquired as coursework. For participation in the examination the coursework must have been acquired. Whether the examination is written or oral is decided by the instructor with approval by the head of the examination board.

Literature

Possible References :

- Lars Valerian Ahlfors: Complex analysis. McGraw-Hill 1979.
- John B. Conway: Functions of one complex variable. Springer 1996.
- Wolfgang Fischer, Ingo Lieb: Einführung in die Komplexe Analysis. Springer 2010.
- Walter Rudin: Reelle und komplexe Analysis. Oldenbourg 2009.
- Earl A. Coddington, Norman Levinson: Theory of ordinary differential equations. McGraw-Hill 1955.
- William T. Reid: Ordinary differential equations. John Wiley & Sons 1971.
- Hille, Einar: Ordinary differential equations in the complex domain. Dover Publications 1997.
- Wasow, Wolfgang: Asymptotic expansions for ordinary differential equations. John Wiley 1965.

Transfer

If applicable the module is a prerequisite for the module Master Thesis.

Prerequisites

At least two of the exercise certficates from the module Foundations of Mathematics must have been acquired. One of these must be the exercise certificate from linear algebra 1.

Responsible Persons

Anton Deitmar, Reiner Schätzle

Abbreviations:

Grading System	: g=graded, ng=not graded
Examination Type	: MT=master's thesis, or.=oral exam, wr.=written exam, Pr=presentation, E=essay, P=portfolio, T=continous assessment tests
Teaching Format	: L=lecture, LE=lecture with integrated exercises, SL=seminar or lecture, E=exercise class, T=revision course, P=practical course, PS=introductory seminar, S=seminar, IC=inverted classroom
Status	: o=obligatory, f=facultative
Other	: h=hours, o.=or, s.M.=see module description, SWS=contact hours per week

Module Number: **MAT-20-03**	**Module Title:** Algebra		**Type of Module:** Compulsory Module
ECTS-Points	9		
Workload **- Time in Class** **- Self-Study**	Workload: 270 h	Time in Class: 90 h	Self-Study: 180 h
Duration	1 Semester		
Frequency	regularly in Summer Semester		
Term	2-3		
Language of Instruction	German		
Forms of Teaching and Learning	Lecture 4 SWS + Ex.cl. 2 SWS		
Content	• Groups and structure theory of finite groups. • Rings, ideals, polynomial rings, divisibility theory. • Fields and field extensions. • Geometric and algebraic applications of field theory.		
Objectives	The students deepen their structural thinking, know basic algebraic concepts and can apply them on other mathematical disciplines. They understand, in particular, through the example of field theory, how the interaction of different branches of algebra leads to new insights, e.g. answers to classical problems from antiquity. In the process they have experienced, that the coaction of different areas of mathematics can be essential for solving concrete problems. In the exercise classes they have acquired a confident, precise and independent handling of the terms, statements and methods of the lecture. Furthermore the presentation and communication skills of the students was trained by written assignments and presenting their own solutions. The students are capable of adopting knowledge by self-study and at the same time their capacity for teamwork was enhanced by working in small groups.		

Requirements for obtaining Credits / Grading (Weighting if applicable)

Title	Type of Course	Status	SWS	ECTS	Coursework	Type of Exam	Dur. of Exam (min)	Grading	Weight for Grade
Algebra	L	o	4	6	yes	wr. o. or.	90-180 o. 20-30	g	100
	E	o	2	3					

In this module an exercise certificate is to be acquired as coursework. For participation in the examination the coursework must have been acquired. Whether the examination is written or oral is decided by the instructor with approval by the head of the examination board.

Literature	**Possible References :** • Siegfried Bosch: Algebra. Springer 2009. • Gerd Fischer, Reinhard Sacher: Einführung in die Algebra. Teubner 1983. • Christian Karpfinger, Kurt Meyberg: Algebra: Gruppen-Ringe-Körper. Springer Spektrum 2010. • Kurt Meyberg: Algebra 1. Hanser 1980. • Kurt Meyberg: Algebra 2. Hanser 1976. • Hans-Jörg Reiffen, Günter Scheja, Udo Vetter: Algebra. Bibliographisches Institut 1984.
Transfer	If applicable, the module is requirement for the module Master Thesis.
Prerequisites	At least two of the exercise certificates from the Foundations of Mathematics module must have been acquired, one of which must be the exercise certificate for Linear Algebra 1. Content-wise, knowledge from the submodule Algebraic Structures is assumed.
Responsible Persons	Jürgen Hausen, Hannah Markwig, Thomas Markwig

Abbreviations:

Grading System	: g=graded, ng=not graded
Examination Type	: MT=master's thesis, or.=oral exam, wr.=written exam, Pr=presentation, E=essay, P=portfolio, T=continous assessment tests
Teaching Format	: L=lecture, LE=lecture with integrated exercises, SL=seminar or lecture, E=exercise class, T=revision course, P=practical course, PS=introductory seminar, S=seminar, IC=inverted classroom
Status	: o=obligatory, f=facultative
Other	: h=hours, o.=or, s.M.=see module description, SWS=contact hours per week

Module Number: MAT-20-11	**Module Title:** Numerical Mathematics		**Type of Module:** Compulsory Module
ECTS-Points	9		
Workload **- Time in Class** **- Self-Study**	Workload: 270 h	Time in Class: 90 h	Self-Study: 180 h
Duration	1 Semester		
Frequency	regularly in Winter Semester		
Term	2-3		
Language of Instruction	German		
Forms of Teaching and Learning	Lecture 4 SWS + Ex.cl. 2 SWS		
Content	• Interpolation and approximation of functions. • Numeric integration and differentiation. • Systems of linear equations and linear curve fitting. • Systems of non-linear equations and non-linear curve fitting. • Initial value problems for ordinary differential equations.		
Objectives	The students know the foundations of numerical mathematics and are capable of performing basic calculation techniques. They understand to bring the knowledge gathered in the modules Analysis and Linear Algbra in the analysis of numerical methods and to use the methods for specific problems. Their algorithmic thinking was enhanced and they are acquainted to the analysis of algorithms with a view to questions of efficiency and complexity. In the exercise classes they have acquired a confident, precise and independent handling of the terms, statements and methods of the lecture. Furthermore the presentation and communication skills of the students were trained by written assignments and presenting their own solutions. The students are capable of adopting knowledge by self-study and at the same time their capacity for teamwork was enhanced by working in small groups.		

Requirements for obtaining Credits / Grading (Weighting if applicable)

Title	Type of Course	Status	SWS	ECTS	Coursework	Type of Exam	Dur. of Exam (min)	Grading	Weight for Grade
Numerical Mathematics	L	o	4	6	yes	wr. o. or.	90-180 o. 20-30	g	100
	E	o	2	3					

In this module an exercise certificate is to be acquired as coursework. For participation in the examination the coursework must have been acquired. Whether the examination is written or oral is decided by the instructor with approval by the head of the examination board.

Literature	**Possible References :** • Peter Deuflhard, Andreas Hohmann: Numerische Mathematik 1. De Gruyter 2008. • Martin Hanke-Bourgeois: Grundlagen der Numerischen Mathematik und des Wissenschaftlichen Rechnens. Vieweg+Teubner 2009.
Transfer	If applicable, the module is prerequisite for the module Master Thesis.

Prerequisites	At least two of the exercise certificates from the module Foundations in Mathematics must have been acquired. One of these must be the certificate for Linear Algebra 1. Furthermore, before admission to the examination, the practical certificate for the practical course in Numerical Analysis from the module Introduction to Scientific Programming must have been obtained.
Responsible Persons	Christian Lubich, Andreas Prohl

Abbreviations:

Grading System	:	g=graded, ng=not graded
Examination Type	:	MT=master's thesis, or.=oral exam, wr.=written exam, Pr=presentation, E=essay, P=portfolio, T=continous assessment tests
Teaching Format	:	L=lecture, LE=lecture with integrated exercises, SL=seminar or lecture, E=exercise class, T=revision course, P=practical course, PS=introductory seminar, S=seminar, IC=inverted classroom
Status	:	o=obligatory, f=facultative
Other	:	h=hours, o.=or, s.M.=see module description, SWS=contact hours per week

<table>
<tr><td>Module Number:
MAT-20-12</td><td colspan="2">Module Title:
Stochastics</td><td>Type of Module:
Compulsory Module</td></tr>
<tr><td>ECTS-Points</td><td colspan="3">9</td></tr>
<tr><td>Workload
- Time in Class
- Self-Study</td><td>Workload:
270 h</td><td>Time in Class:
90 h</td><td>Self-Study:
180 h</td></tr>
<tr><td>Duration</td><td colspan="3">1 Semester</td></tr>
<tr><td>Frequency</td><td colspan="3">regularly in Summer Semester</td></tr>
<tr><td>Term</td><td colspan="3">2-3</td></tr>
<tr><td>Language of Instruction</td><td colspan="3">German</td></tr>
<tr><td>Forms of Teaching and Learning</td><td colspan="3">Lecture 4 SWS + Ex.cl. 2 SWS</td></tr>
<tr><td>Content</td><td colspan="3">Introduction to probability theory and statistics.
Topics from probability theory: Probability spaces, simple conditional probabilities, urn models, random variables, distribution functions, discret and continous distributions, expectation and variance, inequalities, independence, joint probability distribution, notions of convergence, laws of lagre numbers, central limit theorem.
Topics from statistics: Point estimators, hypothesis testing, standard testing methods.</td></tr>
<tr><td>Objectives</td><td colspan="3">The students know the basic principles of stochastics. They have the ability to abstract stochastic questions and are capable of using their knowledge on specific problems.
In the exercise classes they have acquired a confident, precise and independent handling of the terms, statements and methods of the lecture. Furthermore the presentation and communication skills of the students were trained by written assignments and presenting their own solutions. The students are capable of adopting knowledge by self-study and at the same time their capacity for teamwork was enhanced by working in small groups.</td></tr>
<tr><td>Requirements for obtaining Credits / Grading (Weighting if applicable)</td><td colspan="3">
<table>
<tr><th>Title</th><th>Type of Course</th><th>Status</th><th>SWS</th><th>ECTS</th><th>Coursework</th><th>Type of Exam</th><th>Dur. of Exam (min)</th><th>Grading</th><th>Weight for Grade</th></tr>
<tr><td rowspan="2">Stochastics</td><td>L</td><td>o</td><td>4</td><td>6</td><td rowspan="2">yes</td><td rowspan="2">wr. o. or.</td><td rowspan="2">90-180 o. 20-30</td><td rowspan="2">g</td><td rowspan="2">100</td></tr>
<tr><td>E</td><td>o</td><td>2</td><td>3</td></tr>
</table>
In this module an exercise certificate is to be acquired as coursework. For participation in the examination the coursework must have been acquired. Whether the examination is written or oral is decided by the instructor with approval by the head of the examination board.</td></tr>
<tr><td>Literature</td><td colspan="3">Possible References :
Hans-Otto Georgii: Stochastik. De Gruyter 2015.
Ulrich Krengel: Einführung in die Wahrscheinlichkeitstheorie und Statistik. Vieweg 2005.</td></tr>
<tr><td>Transfer</td><td colspan="3">If applicable, the module is prerequisite for the module Master Thesis.</td></tr>
<tr><td>Prerequisites</td><td colspan="3">At least two of the exercise certificates from the module Foundations in Mathematics must have been acquired. One of these must be the certificate for Linear Algebra 1.</td></tr>
<tr><td>Responsible Persons</td><td colspan="3">Martin Möhle, Martin Zerner</td></tr>
</table>

Abbreviations:

Grading System	: g=graded, ng=not graded
Examination Type	: MT=master's thesis, or.=oral exam, wr.=written exam, Pr=presentation, E=essay, P=portfolio, T=continous assessment tests
Teaching Format	: L=lecture, LE=lecture with integrated exercises, SL=seminar or lecture, E=exercise class, T=revision course, P=practical course, PS=introductory seminar, S=seminar, IC=inverted classroom
Status	: o=obligatory, f=facultative
Other	: h=hours, o.=or, s.M.=see module description, SWS=contact hours per week

Module Number: **MAT-50-01**	**Module Title:** Geometry		**Type of Module:** Compulsory Module
ECTS-Points	9		
Workload - Time in Class - Self-Study	Workload: 270 h	Time in Class: 90 h	Self-Study: 180 h
Duration	1 Semester		
Frequency	regularly in Winter Semester		
Term	2-3		
Language of Instruction	German		
Forms of Teaching and Learning	Lecture 4 SWS + Ex.cl. 2 SWS		
Content	• Axiomatic foundation of planar geometry. • Euclidean and non-Euclidean geometry. • Parametrised curves and surfaces.		
Objectives	The students deepen their axiomatic way of thinking and are capable of giving correct proofs. They know the basic principles of geometry, are able to solve concrete problems and know the fundamental links between geometry and topology. The students are capable of naming and proving the essential results of the lecture as well as assessing and explaining the presented connections. In the exercise classes they have acquired a confident, precise and independent handling of the terms, statements and methods of the lecture. They have learned to transfer the methods to new problems, to analyse them and to work on solution strategies on their own or in a team. They are able to present their solutions and, if necessary, defend them in critical discourse.		

Requirements for obtaining Credits / Grading (Weighting if applicable)

Title	Type of Course	Status	SWS	ECTS	Coursework	Type of Exam	Dur. of Exam (min)	Grading	Weight for Grade
Geometry	L	o	4	6	yes	wr. o. or.	90-180 o. 20-30	g	100
	E	o	2	3					

In this module an exercise certificate is to be acquired as coursework. For participation in the examination the coursework must have been acquired. Whether the examination is written or oral is decided by the instructor with approval by the head of the examination board.

Literature	**Possible References :** • Michele Audin: Geometry. Springer 2003. • Marcel Berger: Geometry Revealed: A Jacob's Ladder to Modern Higher Geometry. Springer 2010. • David A. Brannan, Matthew F. Esplen, Jeremy J. Gray: Geometry. Cambridge University Press 2012. • John Stillwell: The four pillars of geometry. Springer 2005.
Transfer	If applicable, the module is a prerequisite for the module master thesis.

Prerequisites	At least two of the exercise certificates from the module Foundations of Mathematics must have been acquired. One of these must be the exercise certificate of Linear Algebra 1.
Responsible Persons	Christoph Bohle, Carla Cederbaum, Hannah Markwig, Ivo Radloff

Abbreviations:

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Examination Type	: MT=master's thesis, or.=oral exam, wr.=written exam, Pr=presentation, E=essay, P=portfolio, T=continous assessment tests
Teaching Format	: L=lecture, LE=lecture with integrated exercises, SL=seminar or lecture, E=exercise class, T=revision course, P=practical course, PS=introductory seminar, S=seminar, IC=inverted classroom
Status	: o=obligatory, f=facultative
Other	: h=hours, o.=or, s.M.=see module description, SWS=contact hours per week

Module Number: MAT-20-20	**Module Title:** Introductory Seminar: Presentations in Mathematics	**Type of Module:** Compulsory Module with Choice
ECTS-Points	3	
Workload - Time in Class - Self-Study	Workload: 90 h; Time in Class: 30 h	Self-Study: 60 h
Duration	1 Semester	
Frequency	every Semester	
Term	2-4	
Language of Instruction	German	
Forms of Teaching and Learning	Introductory seminar, talk, presentation, e-learning, blended learning	
Content	Various topics from the foundations of mathematics.	
Objectives	The students independently work on a coherent mathematical topic and prepare it in a didactical appealing form. They learn how to present their work to a group, how to be responsive to questions regarding the content and how to lead a professional discussion.	

Requirements for obtaining Credits / Grading (Weighting if applicable)

Title	Type of Course	Status	SWS	ECTS	Coursework	Type of Exam	Dur. of Exam (min)	Grading	Weight for Grade
Introductory Seminar	PS	o	2	3	yes	Pr	60-90	g	100

The acquisition of the credit points requires alongside with a successfull presentation the regular active participation in the course, like by asking questions, contributing to a discussion or working on problem tasks. Additionally a written elaboration of the own talk or the issue of a handout for the participants may be required. This further work constitutes the coursework of the module.

Transfer	-
Prerequisites	At least two of the exercise certificates from the module Foundations in Mathematics must have been acquired. One of these must be the certificate for linear algebra 1.
Responsible Persons	The dean of studies at the Department of Mathematics

Abbreviations:

Grading System	: g=graded, ng=not graded
Examination Type	: MT=master's thesis, or.=oral exam, wr.=written exam, Pr=presentation, E=essay, P=portfolio, T=continous assessment tests
Teaching Format	: L=lecture, LE=lecture with integrated exercises, SL=seminar or lecture, E=exercise class, T=revision course, P=practical course, PS=introductory seminar, S=seminar, IC=inverted classroom
Status	: o=obligatory, f=facultative
Other	: h=hours, o.=or, s.M.=see module description, SWS=contact hours per week

Section 3: Knowledge Expansion Mathematics

Module Number: MAT-40-51	**Module Title:** Specialisation		**Type of Module:** Compulsory Module with Choice
ECTS-Points	9		
Workload **- Time in Class** **- Self-Study**	Workload: 270 h	Time in Class: 90 h	Self-Study: 180 h
Duration	1 Semester		
Frequency	every Semester		
Term	3-4		
Language of Instruction	German or English		
Forms of Teaching and Learning	Lecture 4 SWS + Ex.cl. 2 SWS		
Comment	A course must be selected from the catalogue of courses in Section 4.1 of the module handbook, comprising 4 hours of lectures and 2 hours of exercises per week. The approval of additional courses or alternative course formats (e.g., two courses with 2 hours of lectures and 1 hour of exercises each) is at the discretion of the head of the examination board, upon a written request by the student.		
Content	The content is determined by the choice of a course.		
Objectives	The students have acquired in-depth knowledge in a specific area of mathematics and gained further experience in presenting and communicating mathematical topics. They are capable of identifying the key statements of the lecture, reproducing the techniques used for their derivation and proof, and critically evaluating them. Additionally, they can integrate the methodological and theoretical foundations of the chosen mathematical subfield and place them within the broader mathematical context. In the exercise classes they have acquired a confident, precise and independent handling of the terms, statements and methods of the lecture. They have learned to transfer the methods onto new problems, to analyse them and to work on solution strategies on their own or in a team.		

Requirements for obtaining Credits / Grading (Weighting if applicable)

Title	Type of Course	Status	SWS	ECTS	Coursework	Type of Exam	Dur. of Exam (min)	Grading	Weight for Grade
see Comment	L	o	4	6	yes	wr. o. or.	90-180 o. 20-30	g	100
	E	o	2	3					

In this module an exercise certificate is to be acquired as coursework. For participation in the examination the coursework must have been acquired. Whether the examination is written or oral is decided by the instructor with approval by the head of the examination board.

Transfer	If applicable the module is a prerequisite for the modules Seminar Specialisation Mathematics and Master Thesis.
Prerequisites	The modules of Section 1 Foundations of Mathematics must have been completed successfully.
Responsible Persons	The dean of studies at the Department of Mathematics

Abbreviations:

Grading System	: g=graded, ng=not graded
Examination Type	: MT=master's thesis, or.=oral exam, wr.=written exam, Pr=presentation, E=essay, P=portfolio, T=continous assessment tests
Teaching Format	: L=lecture, LE=lecture with integrated exercises, SL=seminar or lecture, E=exercise class, T=revision course, P=practical course, PS=introductory seminar, S=seminar, IC=inverted classroom
Status	: o=obligatory, f=facultative
Other	: h=hours, o.=or, s.M.=see module description, SWS=contact hours per week

Section 4: Didactics of Mathematics

Module Number: MAT-80-01	**Module Title:** Subject Didactics Mathematics 1		**Type of Module:** Compulsory Module
ECTS-Points	3		
Workload - Time in Class - Self-Study	Workload: 90 h	Time in Class: 30 h	Self-Study: 60 h
Duration	1 Semester		
Frequency	regularly in Summer Semester		
Term	2-3		
Language of Instruction	German		
Forms of Teaching and Learning	Lecture, exercise class, proseminar, talk, presentation, e-learning, blended learning, project work, case studies		
Content	**Didactics of Algebra and Arithmetic:** This course deals with the foundations of the didactics of mathematics in the educational plans and in particular the didactic reduction of important basic concepts of algebra and arithmetic to school level, various ways of introducing important concepts of algebra and arithmetic at school and ways of motivating basic algebraic and arithmetic ideas.		
Objectives	Students know the basic didactic principles of teaching concepts and can orientate themselves in the educational plans. They are able to compare and evaluate subject-specific approaches to central concepts in algebra and arithmetic. They have the ability to convey algebraic and arithmetic content in a way that is both student- and subject-orientated.		

Requirements for obtaining Credits / Grading (Weighting if applicable)

Title	Type of Course	Status	SWS	ECTS	Coursework	Type of Exam	Dur. of Exam (min)	Grading	Weight for Grade
Subject Didactics Mathematics 1	LIC	o	2	3	no	K o. mP o. P	90-180 o. 20-30	g	100

Whether the examination is written or oral is decided by the instructor with approval by the head of the examination board.

Transfer	-
Prerequisites	At least two of the exercise certificates from the module Foundations of Mathematics must have been acquired. One of these must be the exercise certificate for Linear Algebra 1.
Responsible Persons	Frank Loose, Walther Paravicini

Abbreviations:

Grading System	: g=graded, ng=not graded
Examination Type	: MT=master's thesis, or.=oral exam, wr.=written exam, Pr=presentation, E=essay, P=portfolio, T=continous assessment tests
Teaching Format	: L=lecture, LE=lecture with integrated exercises, SL=seminar or lecture, E=exercise class, T=revision course, P=practical course, PS=introductory seminar, S=seminar, IC=inverted classroom
Status	: o=obligatory, f=facultative
Other	: h=hours, o.=or, s.M.=see module description, SWS=contact hours per week

Module Number: MAT-80-02	**Module Title:** Subject Didactics Mathematics 2		**Type of Module:** Compulsory Module
ECTS-Points	6		
Workload - Time in Class - Self-Study	Workload: 180 h	Time in Class: 60 h	Self-Study: 120 h
Duration	2 Semester		
Frequency	every Semester		
Term	2-3		
Language of Instruction	German		
Forms of Teaching and Learning	Lecture, exercise, proseminar, talk, presentation, e-learning, blended learning, project work, case studies		
Content	The module consists of the two parts • **didactics of geometry and linear algebra,** • **didactics of analysis and stochastics.** It deals with the didactic reduction of important basic concepts of analysis, linear algebra, geometry or stochastics at school level, various options for introducing important terms in analysis, linear algebra, geometry or stochastics at school as well as motivational options for analytic, geometric and stochastic basic ideas.		
Objectives	Students are familiar with the basic didactic principles of teaching concepts. They are able to compare and evaluate subject-specific approaches to central concepts in analysis, linear algebra, geometry and stochastics. They have the ability to convey geometric and algebraic content in a way that is both student- and subject-orientated.		

Requirements for obtaining Credits / Grading (Weighting if applicable)

Title	Type of Course	Status	SWS	ECTS	Coursework	Type of Exam	Dur. of Exam (min)	Grading	Weight for Grade
Subject Didactics Mathematics 2 – Part 1	SLIC	o	2	3	yes	K o. mP o. R o. H o. P.	90-180 o. 20-30	g	50
Subject Didactics Mathematics 2 – Part 2	SLIC	o	2	3	yes	K o. mP o. R o. H o. P.	90-180 o. 20-30	g	50

The module consists of two parts, for which the teaching learning methods (lecture, exercise class or seminar) as well as the type of examination (written or oral exam, presentation or paper) are usually different. This is taken into account by the fact that, the examination in this module consists of two equally weighted parts.

Transfer	-
Prerequisites	The module Foundations of Mathematics must be completed. The module Geometry should be taken parallel to the Didactics of Geometry or should have been taken beforehand, as knowledge from the module Geometry is required in the Didactics of Geometry module.
Responsible Persons	Frank Loose, Walther Paravicini

Abbreviations:

Grading System	: g=graded, ng=not graded
Examination Type	: MT=master's thesis, or.=oral exam, wr.=written exam, Pr=presentation, E=essay, P=portfolio, T=continous assessment tests
Teaching Format	: L=lecture, LE=lecture with integrated exercises, SL=seminar or lecture, E=exercise class, T=revision course, P=practical course, PS=introductory seminar, S=seminar, IC=inverted classroom
Status	: o=obligatory, f=facultative
Other	: h=hours, o.=or, s.M.=see module description, SWS=contact hours per week

Module Number: MAT-80-03	**Module Title:** Subject Didactics Mathematics 3		**Type of Module:** Compulsory Module with Choice
ECTS-Points	6		
Workload **- Time in Class** **- Self-Study**	Workload: 180 h	Time in Class: 60 h	Self-Study: 120 h
Duration	2 Semester		
Frequency	every Semester		
Term	3-4		
Language of Instruction	German		
Forms of Teaching and Learning	Lecture, exercise, proseminar, talk, presentation, e-learning, blended learning, project work, case studies		
Content	In the first part varying topics are covered, who are usually related to the teaching profession. However, also other advanced topics in didactics can be covered. In the second part varying topics from didactics will be studied, which can lead up to recent research in didactics.		
Objectives	The students • know subject didactical principles and educational concepts and can evaluate and scrutinise them, • can compare and evaluate subject related approaches to central terms and theorems of the treated fields, • can plan, execute, analyse and evaluate competence oriented mathematical education on the basis of subject didactical concepts, • can motivate the general educating value of mathematical contents and methods and the social importance of mathematics and put it in context with the goals and contents of mathematical education, • can specifically use subject specific media, • can create a portfolio and document important experiences, findings and insights in a structured manner.		

Requirements for obtaining Credits / Grading (Weighting if applicable)

Title	Type of Course	Status	SWS	ECTS	Coursework	Type of Exam	Dur. of Exam (min)	Grading	Weight for Grade
Subject didactics 3: professional knowledge	S	o	2	3	yes	K o. mP o. R o. H	90-180 o. 20-30	g	50
Subject didactics 3: elective specialisation	SV	o	2	3	yes	K o. mP o. R o. H	90-180 o. 20-30	g	50

The module consists of two parts (Professional Knowledge and Elective Specialisation), for which the teaching learning methods (lecture, exercise or seminar) as well as the type of examination (written or oral exam, presentation or paper) are usually different. This is taken into account by the fact that, the examination in this module consists of two equally weighted parts.

Transfer	-

Prerequisites	The participation in the module requires the successful completion of the modules from Section 1 Foundations of Mathematics.
Responsible Persons	Frank Loose, Walther Paravicini

Abbreviations:

Grading System	: g=graded, ng=not graded
Examination Type	: MT=master's thesis, or.=oral exam, wr.=written exam, Pr=presentation, E=essay, P=portfolio, T=continous assessment tests
Teaching Format	: L=lecture, LE=lecture with integrated exercises, SL=seminar or lecture, E=exercise class, T=revision course, P=practical course, PS=introductory seminar, S=seminar, IC=inverted class-room
Status	: o=obligatory, f=facultative
Other	: h=hours, o.=or, s.M.=see module description, SWS=contact hours per week

Section 5: Master Thesis

<table>
<tr><td>Module Number:
MAT-40-53</td><td colspan="2">Module Title:
Master Thesis</td><td>Type of Module:
Compulsory Module</td></tr>
<tr><td>ECTS-Points</td><td colspan="3">15</td></tr>
<tr><td>Workload
- Time in Class
- Self-Study</td><td>Workload:
450 h</td><td>Time in Class:
regularly, as required</td><td>Self-Study:
450 h</td></tr>
<tr><td>Duration</td><td colspan="3">1 Semester</td></tr>
<tr><td>Frequency</td><td colspan="3">every Semester</td></tr>
<tr><td>Term</td><td colspan="3">4</td></tr>
<tr><td>Language of Instruction</td><td colspan="3">German</td></tr>
<tr><td>Forms of Teaching and Learning</td><td colspan="3">Master thesis</td></tr>
<tr><td>Content</td><td colspan="3">The master’s thesis represents the culmination of the master’s degree programme. Under the guidance of a supervisor, students are required to work on a well-defined problem in mathematics (including mathematics education), which may extend to the frontiers of current research. This involves using scientific methods and presenting the results in written form. Specifically, this includes:
formulating a scientific research question in consultation with the supervisor;
independently searching for and studying relevant scientific literature;
formulating appropriate research questions and methodological approaches for their solution;
independently carrying out the project, as well as presenting the project and its results in writing and, if applicable, orally, within the context of the current state of research.
The results should contribute to scientific knowledge.</td></tr>
<tr><td>Objectives</td><td colspan="3">The students:
are capable of familiarising themselves with a problem, which may extend to the frontiers of current research, within a given timeframe and independently developing a solution approach,
can increasingly apply appropriate scientific methods independently and present the results in a scientifically appropriate manner,
are able to independently work on a scientific topic while applying their mathematical methodological knowledge,
deepen their problem-solving skills and can transfer their methodological knowledge,
are able to present the results of their project to a professional audience.</td></tr>
</table>

Requirements for obtaining Credits / Grading (Weighting if applicable)	Title	Type of Course	Status	SWS	ECTS	Coursework	Type of Exam	Dur. of Exam (min)	Grading	Weight for Grade
	Master Thesis	MT	o	-	15	no	MT	-	g	100
	As part of the preparation of the master's thesis, a talk on the topic of the master's thesis is to be given as specified by the supervisor.									
Transfer	-									
Prerequisites	Subject specific prerequisite for admission to the module Master Thesis is besides the general part of the examination regulations the successful completion of all modules from Section 1 Foundations of Mathematics as well as the acquisition of at least further 42 credit points.									
Responsible Persons	The dean of studies at the Department of Mathematics									

Abbreviations:

Grading System	: g=graded, ng=not graded
Examination Type	: MT=master's thesis, or.=oral exam, wr.=written exam, Pr=presentation, E=essay, P=portfolio, T=continous assessment tests
Teaching Format	: L=lecture, LE=lecture with integrated exercises, SL=seminar or lecture, E=exercise class, T=revision course, P=practical course, PS=introductory seminar, S=seminar, IC=inverted classroom
Status	: o=obligatory, f=facultative
Other	: h=hours, o.=or, s.M.=see module description, SWS=contact hours per week

4 Courses for the Module Specialisation

4.1 Catalogue of Courses

The following lists the courses that can be included in the module Specialisation (MAT-40-51). Other courses may be approved upon written request to the head of the examination board.

Course Title:	Algebraic Topology 1		
Specialisation	Geometry		
Workload **- Time in Class** **- Self-Study**	Workload: 270 h	Time in Class: 90 h	Self-Study: 180 h
Frequency	not regularly		
Language of Instruction	German		
Forms of Teaching and Learning	Lecture 4 SWS + Exercise class 2 SWS		
Content	• Set theoretical topology. • Basic concepts of category theory. • The fundamental group of a punctured topological space. • Theory of covering spaces. • Basic concepts of singular homology theory. • Applications.		
Special Objectives	The students learn how to realise ideas in topology, e.g. the detection of holes in topological spaces, into a precise theory, even with a sophisticated technique. In particular, they recognise how abstract concepts, e.g. from category theory and homological algebra, provide effective ways of speaking that enable the formation of ideas to be adequately implemented.		
Literature	**Possible References :** • Allen Hatcher: Algebraic topology. Cambridge University Press 2009. • Horst Schubert: Topologie. Teubner 1971. • Edwin H. Spanier: Algebraic topology. McGraw-Hill 1966. • Ralph Stöcker, Heiner Zieschang: Algebraische Topologie. Teubner 1994.		
Responsible Persons	Anton Deitmar, Frank Loose		

Course Title:	Algorithms of Numerical Mathematics		
Specialisation	Scientific Computing		
Workload **- Time in Class** **- Self-Study**	Workload: 270 h	Time in Class: 90 h	Self-Study: 180 h
Frequency	regularly		
Language of Instruction	German		
Forms of Teaching and Learning	Lecture 4 SWS + Exercise class 2 SWS		

Content	Advanced, important algorithms of numerics (without differential equations) such as: • Fast Fourier transformation; • QR algorithms for the calulation of eigenvalues; • Method of conjugated gradients and more general Krylov space methods as iterative methods in numeric linear algebra and in non-linear optimisation; • Simplex method and interior point methods in linear optimisation.
Special Objectives	The students have learned the key concepts, results, and methods of algorithmic numerical mathematics.
Literature	**Possible References :** • Peter Deuflhard, Andreas Hohmann: Numerische Mathematik 1. De Gruyter 2008. • Martin Hanke-Bourgeois: Grundlagen der Numerischen Mathematik und des Wissenschaftlichen Rechnens. Vieweg 2009.
Responsible Persons	Christian Lubich, Andreas Prohl

Course Title:	Introduction to Mathematical Logic		
Specialisation	Analysis		
Workload - Time in Class - Self-Study	Workload: 90 h	Time in Class: 30 h	Self-Study: 60 h
Frequency	not regularly		
Language of Instruction	German		
Forms of Teaching and Learning	Lecture 2 SWS		
Content	• Propositional logic. • Languages of the first order: – Completeness and compactness. • Theory of computations: – Register machines; – Gödelisation. • Incompleteness of arithmetic: – First and second incompleteness theorem. • Set theory: – Ordinal- and cardinal numbers; – Incompleteness of set theory.		
Special Objectives	Students are able to understand mathematical theorems and theories in the context of mathematical logic. They understand the limits of possible mathematical knowledge, recognise the difference between truth and provability and can apply basic theoretical model thinking to mathematical content.		

Literature	**Possible References :** • Rautenberg, Wolfgang: Einführung in die Mathematische Logik. Vieweg+Teubner 2008. • Ziegler, Martin: Mathematische Logik. Birkhäuser 2016.
Responsible Persons	Anton Deitmar

Course Title:	Introduction to set theory		
Specialisation	Analysis		
Workload - Time in Class - Self-Study	Workload: 90 h	Time in Class: 30 h	Self-Study: 60 h
Frequency	not regularly		
Language of Instruction	German		
Forms of Teaching and Learning	Lecture 2 SWS		
Content	**Content:** •		
Special Objectives	-		
Literature	**Possible References :** •		
Responsible Persons	Frank Loose		

Course Title:	Introduction to Optimisation		
Specialisation	Scientific Computing		
Workload - Time in Class - Self-Study	Workload: 180 h	Time in Class: 60 h	Self-Study: 120 h
Frequency	not regularly		
Language of Instruction	German		
Forms of Teaching and Learning	Lecture 3 SWS + Exercise class 1 SWS		

Content	• Optimality theory for smooth, convex and linear optimisation problems optimisation problems with constraints. • Foundations of the theory of convex sets and functions. • Duality theory for convex and linear optimisation problems. • Solution methods for linear optimisation problems.
Special Objectives	Students know and understand methods and algorithms for solving convex and linear optimisation problems. They have learnt to apply the methods to simple problems related to economics, technology or physics. They will be able to critically assess the possibilities and limitations of using the methods.
Literature	**Possible References :** • Florian Jarre, Joseph Stoer: Optimierung: Einführung in mathematische Theorie und Methoden. Springer 2019. • Jorge Nocedal, Stephen J. Wright: Numerical optimization. Springer 2006.
Responsible Persons	Christian Lubich

Course Title:	Introduction to Dynamical Systems		
Specialisation	Analysis		
Workload - Time in Class - Self-Study	Workload: 90 h	Time in Class: 30 h	Self-Study: 60 h
Frequency	not regularly		
Language of Instruction	German or English		
Forms of Teaching and Learning	Lecture 2 SWS		
Content	• Kepler's laws. • Equilibrium positions. • Stability. • Predator-prey model. • Poincaré-Bendixson theorem. • Limit sets. • Periodic orbits. • Celestial mechanics.		
Special Objectives	The students can ask and examine qualitative questions about the solutions of ordinary differential equations, like e.g.: How long do mathematical solutions exist? Are there equilibrium states or periodic orbits? When are trajectories stable?		

Literature	**Possible References :** • Morris W. Hirsch, Stephen Smale: Differential equations, dynamical systems, and linear algebra. Academic Press 1974. • Vladimir I. Arnold: Mathematical methods of classical mechanics. Springer 2010. • Carl Ludwig Siegel, Jürgen Moser: Lectures on celestial mechanics. Springer 1995.
Responsible Persons	Frank Loose

Course Title:	Introduction to Geometric Measure Theory		
Specialisation	Analysis		
Workload - Time in Class - Self-Study	Workload: 270 h	Time in Class: 90 h	Self-Study: 180 h
Frequency	not regularly		
Language of Instruction	German or English		
Forms of Teaching and Learning	Lecture 4 SWS + Exercise class 2 SWS		
Content	• Measures, covering theorems, differentiation of measures, Hausdorff measures and densities. • Isodiametric inequality. • Rademacher's theorem and Whitney's embedding theorem. • Surface- and cosurface formula. • Countable rectifiable sets, rectifiable varifolds.		
Special Objectives	Students have familiarised themselves with an important mathematical field that combines analysis and geometry and whose concepts and methods can be successfully applied to various problems. They have familiarised themselves with the basic concepts, results and methods of geometric measure theory and can successfully apply these methods in further courses.		
Literature	**Possible References :** • Lawrence C. Evans, Ronald F. Gariepy: Measure theory and fine properties of functions. CRC Press 1992. • Herbert Federer: Geometric measure theory. Springer 1969. • Leon Simon: Lectures on geometric measure theory. Australian National University 1984.		
Responsible Persons	Reiner Schätzle		

Course Title:	Introduction to Geometric Measure Theory – Measure Theoretic Methods
Specialisation	Analysis

Workload **- Time in Class** **- Self-Study**	Workload: 150 h	Time in Class: 45 h	Self-Study: 105 h
Frequency	not regularly		
Language of Instruction	German or English		
Forms of Teaching and Learning	Lecture 2 SWS + Exercise class 1 SWS		
Content	• Measures, covering theorems, differentiation of measures, Hausdorff measures and densities. • Isodiametric inequality. • Rademacher's theorem and Whitney's embedding theorem.		
Special Objectives	Students have familiarised themselves with an important mathematical field that combines analysis and geometry and whose concepts and methods can be successfully applied to various problems. They have familiarised themselves with the basic concepts, results and methods of geometric measure theory and can successfully apply these methods in further courses.		
Literature	**Possible References :** • Lawrence C. Evans, Ronald F. Gariepy: Measure theory and fine properties of functions. CRC Press 1992. • Herbert Federer: Geometric measure theory. Springer 1969. • Leon Simon: Lectures on geometric measure theory. Australian National University 1984.		
Responsible Persons	Reiner Schätzle		

Course Title:	Introduction to Geometric Measure Theory – Varifolds		
Specialisation	Analysis		
Workload **- Time in Class** **- Self-Study**	Workload: 150 h	Time in Class: 45 h	Self-Study: 105 h
Frequency	not regularly		
Language of Instruction	German or English		
Forms of Teaching and Learning	Lecture 2 SWS + Exercise class 1 SWS		
Content	• Surface- and cosurface formula. • Countable rectifiable sets, rectifiable varifolds.		
Special Objectives	Students have familiarised themselves with an important mathematical field that combines analysis and geometry and whose concepts and methods can be successfully applied to various problems. They have familiarised themselves with basic concepts, results and methods of geometric measure theory and can successfully apply these methods in further courses.		

Literature	**Possible References :** • Lawrence C. Evans, Ronald F. Gariepy: Measure theory and fine properties of functions. CRC Press 1992. • Herbert Federer: Geometric measure theory. Springer 1969. • Leon Simon: Lectures on geometric measure theory. Australian National University 1984.
Responsible Persons	Reiner Schätzle

Course Title:	Introduction to Commutative Algebra and Algebraic Geometry		
Specialisation	Algebra		
Workload - Time in Class - Self-Study	Workload: 270 h	Time in Class: 90 h	Self-Study: 180 h
Frequency	regularly in Winter Semester		
Language of Instruction	German		
Forms of Teaching and Learning	Lecture 4 SWS + Exercise class 2 SWS		
Content	• Rings and ideals. • Gröbner bases. • Localization. • Noetherian rings and modules. • Integral ring extensions. • Krull's principal ideal theorem and dimension theory. • Hilbert's Nullstellensatz and Noether normalisation. • Affine varieties, Zariski topology, morphisms.		
Special Objectives	The students have become familiar with the central concepts, results, and methods of commutative algebra and affine algebraic geometry. They have experienced the profound interplay between algebra and geometry through the example of affine varieties. Furthermore, the students understand how adopting a higher perspective - namely, abstracting the problem - enables the simultaneous treatment and resolution of seemingly unrelated questions.		

Literature	**Possible References :** • Michael Francis Atiyah, Ian G. Macdonald: Introduction to commutative algebra. Addison Wesley 1969. • David A. Cox, John B. Little, Donal O'Shea: Ideals, varieties, and algorithms. Springer 2008. • David Eisenbud: Commutative algebra with a view toward algebraic geometry. Springer 1995. • Ernst Kunz: Einführung in die kommutative Algebra und algebraische Geometrie. Vieweg 1980. • Miles Reid: Undergraduate Commutative Algebra. Cambridge University Press 1997.
Responsible Persons	Jürgen Hausen

Course Title:	Introduction to Partial Differential Equations		
Specialisation	Analysis		
Workload - Time in Class - Self-Study	Workload: 270 h	Time in Class: 90 h	Self-Study: 180 h
Frequency	regularly		
Language of Instruction	English		
Forms of Teaching and Learning	Lecture 4 SWS + Exercise class 2 SWS		
Content	• Harmonic functions. • Maximum principles. • Sobolev spaces. • L^2 theory. • Important examples (Laplace equation, wave equation, heat equation). • Fundamental solutions (elliptic situation). • Weak solutions of elliptic equations.		
Special Objectives	The students got to know a central branch of analysis, whose terms and methods are fundamental for many fields, like numerics or stochastics. Also evolutionary equations, who have strong connections to geometry, are issue of the lecture. The students are acquainted with central terms, results and methods of linear partial differential equations and are able to use these methods in advanced courses.		
Literature	**Possible References :** • Lawrence C. Evans: Partial differential equations. American Mathematical Society 2010. • David Gilbarg, Neil S. Trudinger: Elliptic partial differential equations of second order. Springer 2001. • Olga A. Ladyzenskaja, Vsevolod A. Solonnikov, Nina N. Uralceva: Linear and quasilinear equations of parabolic type. AMS 1968.		

Responsible Persons	Gerhard Huisken, Reiner Schätzle

Course Title:	Introduction to Partial Differential Equations – Part 1		
Specialisation	Analysis		
Workload - Time in Class - Self-Study	Workload: 150 h	Time in Class: 45 h	Self-Study: 105 h
Frequency	not regularly		
Language of Instruction	German or English		
Forms of Teaching and Learning	Lecture 2 SWS + Exercise class 1 SWS		
Content	• Harmonic functions. • Maximum principles. • Sobolev spaces.		
Special Objectives	The students have familiarised themselves with the first basic features of a central area of analysis, the concepts and methods of which are fundamental for many other areas, such as numerics and stochastics. Students are familiar with the central concepts, results and methods of linear partial differential equations and can successfully apply these methods in the more advanced courses.		
Literature	**Possible References :** • Lawrence C. Evans: Partial differential equations. American Mathematical Society 2010. • David Gilbarg, Neil S. Trudinger: Elliptic partial differential equations of second order. Springer 2001. • Olga A. Ladyzenskaja, Vsevolod A. Solonnikov, Nina N. Uralceva: Linear and quasilinear equations of parabolic type. AMS 1968.		
Responsible Persons	Gerhard Huisken, Reiner Schätzle		

Course Title:	Elementary Number Theory		
Specialisation	Algebra		
Workload - Time in Class - Self-Study	Workload: 180 h	Time in Class: 60 h	Self-Study: 120 h
Frequency	not regularly		
Language of Instruction	German		
Forms of Teaching and Learning	Lecture 2 SWS + Exercise class 2 SWS		

Content	• Divisibility in the integers. • Prime numbers. • Congruences. • Quadratic residues. • Arithmetic functions. • Multiplicative functions. • Classical theorems. • Applications.
Special Objectives	Students deepen their basic knowledge of integers and experience applying this knowledge to mathematical problems of various kinds.
Literature	**Possible References :** • Friedhelm Padberg: Elementare Zahlentheorie. Spektrum Akademischer Verlag 2001. • Stefan Mueller-Stach, J. Piontkowski: Elementare und algebraische Zahlentheorie. Vieweg 2006.
Responsible Persons	Victor Batyrev, Thomas Markwig

Course Title:	Functional Analysis		
Specialisation	Analysis		
Workload **- Time in Class** **- Self-Study**	Workload: 270 h	Time in Class: 90 h	Self-Study: 180 h
Frequency	regularly		
Language of Instruction	German or English		
Forms of Teaching and Learning	Lecture 4 SWS + Exercise class 2 SWS		
Content	• Normed spaces, Banach spaces, dual spaces. • Hahn-Banach theorem, uniform boundedness principle. • Closed graph theorem, open mapping theorem, Banach-Alaoglu theorem. • Compact operators, normal operators, spectral theorems.		
Special Objectives	The students are aquainted with the basic principles and techniques of the theory of infinte dimensional spaces and can apply them to problems in analysis and geometry. They understand the complexity of problems of spectral theory and can use its results for the solution of analytical problems.		

Literature	**Possible References :** • Nicolas Bourbaki: Topological vector spaces. Springer 1987. • Adam Bowers, Nigel Dalton: An introductory course in functional analysis. Springer 2014. • Harro Heuser: Funktionalanalysis. Teubner 2006. • Markus Haase: Functional analysis. American Mathematical Society 2014. • Peter D. Lax: Functional analysis. Wiley 2002. • Gert Kjaergaard Pedersen: Analysis now. Springer 1995. • Walter Rudin: Functional analysis. McGraw-Hill 1991. • Dirk Werner: Funktionalanalysis. Springer 2011. • Kosaku Yosida: Functional analysis. Springer 1995. • Hans Wilhelm Alt: Lineare Funktionalanalysis. Springer 2012.
Responsible Persons	Carla Cederbaum, Anton Deitmar, Gerhard Huisken, Reiner Schätzle

Course Title:	Geometry of Manifolds 1		
Specialisation	Geometry		
Workload **- Time in Class** **- Self-Study**	Workload: 270 h	Time in Class: 90 h	Self-Study: 180 h
Frequency	not regularly		
Language of Instruction	German or English		
Forms of Teaching and Learning	Lecture 4 SWS + Exercise class 2 SWS		
Content	• Manifolds and submanifolds. • Vector fields and flows. • Metrics, foundations of Riemannian geometry. • Complex structures. • Theorem of Gauß-Bonnet on surfaces.		
Special Objectives	The students know and understand the fundamental concepts of real and complex differential geometry and the basic techniques for handling them. Especially they have deepened their understanding of differential and integral calculus and have exemplarily experienced how mathematical concepts are used in a natural way in geometry.		

Literature	**Possible References :** • Sylvestre Gallot, Dominique Hulin, Jacques Lafontaine: Riemannian Geometry. Springer 2004. • John M. Lee: Introduction to Smooth Manifolds. Springer 2012. • Liviu I. Nicolaescu: Lectures On The Geometry Of Manifolds. World Scientific 1996. • Clifford Henry Taubes: Differential Geometry: Bundles, Connections, Metrics and Curvature. Oxford University Press 2011.
Responsible Persons	Christoph Bohle, Frank Loose

Course Title:	Geometry in Physics		
Specialisation	Mathematical Physics		
Workload - Time in Class - Self-Study	Workload: 270 h	Time in Class: 90 h	Self-Study: 180 h
Frequency	regularly in Winter Semester		
Language of Instruction	English		
Forms of Teaching and Learning	Lecture 4 SWS + Exercise class 2 SWS		
Content	The module provides an introduction to fundamental methods of differential geometry and their relevance for physics. Particular topics are manifolds, differential forms, Riemannian metrics and associated notions of curvature, Riemannian geometry of submanifolds, real vector bundles, and connections. Applications of these concepts in Physics are discussed.		
Special Objectives	Students obtain knowledge, understanding, and acquaintance with the use of the listed notions of differential geometry. They develop, in particular, a deeper understanding of differential and integral calculus and experience through examples how the mathematical notions are naturally applied within physical theories.		
Literature	**Possible References :** • John Lee: Introduction to smooth manifolds. Springer 2012. • John Lee: Riemannian manifolds: An introduction. Springer 1997. • Chris Isham: Modern differential geometry for physicists. World Scientific 1999. • Mikio Nakahara: Geometry, Topology and Physics. IOP Publishing 2003.		
Responsible Persons	Christoph Bohle, Carla Cederbaum, Stefan Teufel		

Course Title:	Foundations of Discrete Mathematics		
Specialisation	Stochastics		
Workload - Time in Class - Self-Study	Workload: 270 h	Time in Class: 90 h	Self-Study: 180 h

Frequency	not regularly
Language of Instruction	German
Forms of Teaching and Learning	Lecture 4 SWS + Exercise class 2 SWS
Content	• Logic. • Sets, relations, functions. • Partial orders. • Combinatorics. • Number theory. • Graph theory. • Algorithms and formal languages. • Discrete optimization.
Special Objectives	Students have learned how to use basic methods of discrete mathematics. They can analyze discrete structures and identify discrete structures in different contexts.
Literature	**Possible References :** • Ronald Graham, Donald Knuth, Oren Patashnik: Concrete Mathematics. Addison-Wesley 1994. • Kenneth H. Rosen: Discrete Mathematics and Its Application. McGraw-Hill 2019. • Ralph P. Grimaldi: Discrete and Combinatorial Mathematics. Addison-Wesley 2004. • Norman L. Biggs: Discrete Mathematics. Oxford University Press 2002.
Responsible Persons	Martin Möhle, Martin Zerner, Elmar Teufl

Course Title:	Hyperbolic Geometry: Axiomatic, Reflection Geometric, Algebraic		
Specialisation	Geometry		
Workload - Time in Class - Self-Study	Workload: 270 h	Time in Class: 90 h	Self-Study: 180 h
Frequency	not regularly		
Language of Instruction	German		
Forms of Teaching and Learning	Lecture 4 SWS + Exercise class 2 SWS		
Content	Starting from a system of axioms for plane absolute geometry with the basic concepts of incidence and congruence, the associated Bachmann reflection geometry is developed. After the introduction of the hyperbolic axiom, this is continued with reflection-geometric end theory. A Euclidean field is created from the rotations around an end and the translations along a straight line, with the help of which the hyperbolic plane under consideration is described algebraically.		

Special Objectives	The students have learnt to look at one and the same mathematical object (in this case absolute and hyperbolic planes) from completely different perspectives and to link them together. In particular, they have learnt about Bachmann's group-theoretically oriented reflection geometry, which rarely appears in the curriculum, and thus deepen their knowledge of groups. They also deepened their knowledge about the interweaving of geometry and algebra.
Literature	**Possible References :** • Friedrich Bachmann: Aufbau der Geometrie aus dem Spiegelungsbegriff. Springer 1959. • Robin Hartshorne: Geometry: Euclid and beyond. Springer 2000. • Helmut Karzel, Kay Sörensen, Dirk Windelberg: Einführung in die Geometrie. Vandenhoeck und Ruprecht 1973.
Responsible Persons	Hermann Hähl, Hannah Markwig

Course Title:	Measure and Integration Theory		
Specialisation	Analysis		
Workload - Time in Class - Self-Study	Workload: 270 h	Time in Class: 90 h	Self-Study: 180 h
Frequency	regularly in Winter Semester		
Language of Instruction	German		
Forms of Teaching and Learning	Lecture 4 SWS + Exercise class 2 SWS		
Content	• Measures and integrals. • Lebesgue integral, Fubini's theorem, transformation formula. • Convergence theorems. • L^p-spaces, Radon-Nikodym theorem and Riesz representation theorem. • Submanifolds in the $\mathbb{R}^n$, differential forms, Stokes' theorem.		
Special Objectives	The students know the basic terms, constructions, results and proving methods of integration theory in several real variables and in general measure spaces. Furthermore they are able to calculate the surface contents and the volumes even of complex bodies as well as multidimensional integrals. They have learned to transfer abstract questions of the subject into concrete problems and know important applications, e.g. in probability theory and physics.		

Literature	**Possible References :** • Heinz Bauer: Wahrscheinlichkeitstheorie und Grundzüge der Maßtheorie. De Gruyter 1978. • Anton Deitmar: Analysis. Springer Spektrum 2017. • Jürgen Elstrodt: Maß- und Integrationstheorie. Springer 2011. • Lawrence C. Evans, Ronald F. Gariepy: Measure theory and fine properties of functions. CRC Press 1992. • Otto Forster: Analysis 3. Friedr. Vieweg+Teubner 2011. • Edwin Hewitt, Karl Robert Stromberg: Real and Abstract Analysis. Springer 1975. • Georg Nöbeling: Integralsätze der Analysis. De Gruyter 1979. • Walter Rudin: Reelle und komplexe Analysis. Oldenbourg 2009.
Responsible Persons	Anton Deitmar, Reiner Schätzle

Course Title:	Commutative Algebra		
Specialisation	Algebra		
Workload **- Time in Class** **- Self-Study**	Workload: 270 h	Time in Class: 90 h	Self-Study: 180 h
Frequency	regularly in Winter Semester		
Language of Instruction	German or English		
Forms of Teaching and Learning	Lecture 4 SWS + Exercise class 2 SWS		
Content	• Rings and Ideals. • Localisation and local rings. • Noetherian and Artinian rings and modules. • Integral ring extensions and Cohen-Seidenberg theorems. • Krull's principal ideal theorem and dimension theory. • Primary decomposition. • Normality, regularity and discrete valuation rings. • Hilbert's Nullstellensatz and Noether normalisation.		
Special Objectives	The students are familiar with and understand the language and methods of commutative algebra, which are essential for studying the fields of algebra, geometry, and number theory. They recognise how adopting a higher perspective - namely, abstracting the problem - enables the simultaneous treatment and resolution of seemingly unrelated questions.		

Literature	**Possible References :** • Michael Francis Atiyah, Ian G. Macdonald: Introduction to commutative algebra. Addison Wesley 1969. • David A. Cox, John B. Little, Donal O'Shea: Ideals, varieties, and algorithms. Springer 2008. • David Eisenbud: Commutative algebra with a view toward algebraic geometry. Springer 1995. • Ernst Kunz: Einführung in die kommutative Algebra und algebraische Geometrie. Vieweg 1980. • Miles Reid: Undergraduate Commutative Algebra. Cambridge University Press 1997.
Responsible Persons	Victor Batyrev, Thomas Markwig

Course Title:	Convex Geometry		
Specialisation	Geometry		
Workload - Time in Class - Self-Study	Workload: 270 h	Time in Class: 90 h	Self-Study: 180 h
Frequency	not regularly		
Language of Instruction	German or English		
Forms of Teaching and Learning	Lecture 4 SWS + Exercise class 2 SWS		
Content	• Cones, polytopes, polyhedra, fans, polyedral complexes. • Normal fans of polygons. • Triangulations, subdivisions, secondary fans, discriminants.		
Special Objectives	In the lecture the students learn basic terms, results and methods of convex geometry. They develope a deepened understanding for the concept of duality of mathematical objects on the example of polytopes and fans. Furthermore they enhance their geometric view and their spatial sense.		
Literature	**Possible References :** • Günter M. Ziegler: Lectures on Polytopes. Springer 1998.		
Responsible Persons	Hannah Markwig		

Course Title:	Cryptography		
Specialisation	Algebra		
Workload - Time in Class - Self-Study	Workload: 150 h	Time in Class: 45 h	Self-Study: 105 h

Frequency	not regularly
Language of Instruction	German or English
Forms of Teaching and Learning	Lecture 2 SWS + Exercise class 1 SWS
Content	• Brief review of key concepts and results from algebra and number theory. • Historical ciphers and their cryptanalysis (Caesar, Vigenere, substitution); encryption schemes. • Diffie-Hellman protocol and fast exponentiation. • Discrete logarithms: Shanks' algorithm and Pollard's rho method. • RSA: correctness, security, and attacks. • Signature schemes.
Special Objectives	Students are familiar with the fundamental concepts and results of elementary number theory and algebra, as well as their application in cryptography. They can implement the methods covered in Python or SageMath in an exemplary manner and know what to pay attention to. Using classical ciphers, they understand typical strengths and weaknesses; they master the Diffie-Hellman protocol and are familiar with the man-in-the-middle attack. They can compute discrete logarithms in cyclic groups, understand the RSA scheme, and are able to interpret the recommendations of the Federal Office for Information Security (BSI). In various attack scenarios, they can identify weaknesses of RSA when the requisite conditions are not met. By engaging with numerous open problems in cryptography – whose solution approaches can, perhaps surprisingly, stem from very different areas of mathematics – students practise critical thinking. The exercises are central and support students in working independently and in a practice-oriented way, especially with CAS systems such as SageMath.
Literature	**Possible References :** • Jeffrey Hoffstein, Jill Pipher, Joseph H. Silverman: An introduction to mathematical cryptography. Springer 2008. • Christian Karpfinger, Hubert Kiechle: Kryptologie, Algebraische Methoden und Algorithmen, Vieweg 2010. • Dan Boneh, Victor Shoup: A Graduate Course in Applied Cryptography. 2023 (online Version: https://toc.cryptobook.us/). • Jonathan Katz, Yehuda Lindell: Introduction to Modern Cryptography. Chapman and Hall/CRC 2020.
Responsible Persons	Thomas Markwig

Course Title:	Lie Groups		
Specialisation	Analysis		
Workload **- Time in Class** **- Self-Study**	Workload: 270 h	Time in Class: 90 h	Self-Study: 180 h
Frequency	not regularly		
Language of Instruction	German or English		

Forms of Teaching and Learning	Lecture 4 SWS + Exercise class 2 SWS
Content	• Manifolds and Lie groups, • Lie algebras and exponential map, • Covering spaces and classification of Lie groups by their Lie algebras, • Classical Lie groups, • Operations of Lie groups and homogeneous spaces.
Special Objectives	Lie groups lie at the interface between geometry, algebra and analysis. They are suitable for describing the symmetries of geometric objects, but also algebraic equations or solutions of differential equations, in particular if these symmetries form a continuous set. The students learn from a prominent example how different disciplines of mathematics can work together very successfully and how a convincing formalism is developed that can precisely describe a variety of symmetry phenomena.
Literature	**Possible References :** • Joachim Hilgert, Karl-Hermann Neeb: Liegruppen und Lie-Algebren. Vieweg 1991. • Gerhard P. Hochschild: The structure of Lie groups. Holden-Day 1965. • Frank W. Warner: Foundations of differentiable manifolds and Lie groups. Springer 1983.
Responsible Persons	Anton Deitmar, Frank Loose

Course Title:	Linear Control Theory		
Specialisation	Analysis		
Workload - Time in Class - Self-Study	Workload: 180 h	Time in Class: 60 h	Self-Study: 120 h
Frequency	not regularly		
Language of Instruction	German		
Forms of Teaching and Learning	Lecture 2 SWS + Exercise class 2 SWS		
Content	Mathematical methods are indispensable for the management and control of complex systems and processes. The underlying theory is not only fascinating due to its diverse applications, but also, in its abstract form, due to the clarity and elegance of its methods and results. In this lecture, finite-dimensional systems are dealt with first, for which a good knowledge of analysis and linear algebra is sufficient. The aims are Kalman's controllability criterion and the resulting criteria for stabilisability. If there is enough time, we will extend the theory to infinite-dimensional systems. In the exercise classes we will apply the theory to concrete examples.		
Special Objectives	Students have learnt basic methods of linear control theory. At the same time, they have experienced and understood the interaction of various theoretical concepts from linear algebra and analysis and their benefits for specific applications.		

Literature	**Possible References :** • Hans Wilhelm Knobloch, Huibert Kwakernaak: Lineare Kontrolltheorie. Springer 1985. • Jerzy Zabczyk: Mathematical Control Theory. Birkhäuser 1992. • Ruth F. Curtain, Hans Zwart: An Introduction to Infinite-Dimensional Systems Theory. Springer 1995.
Responsible Persons	Rainer Nagel

Course Title:	Non-Linear Optimisation		
Specialisation	Scientific Computing		
Workload **- Time in Class** **- Self-Study**	Workload: 270 h	Time in Class: 90 h	Self-Study: 180 h
Frequency	regularly		
Language of Instruction	German		
Forms of Teaching and Learning	Lecture 4 SWS		
Content	• Finite-dimensional optimisation, gradient method with Armijo's rule, globalised Newton method. • Restricted optimisation, Farkas' lemma, tangent cone. • Abadie CQ, KKT conditions, Slater conditions. • Linear programme, duality, simplex method. • Penalty and barrier methods, interior point method. • Nonlinear programs, SQP methods, non-smooth optimisation.		
Special Objectives	Students master the basic principles and techniques of analysis and numerics of constrained optimisation problems.		
Literature	**Possible References :** • Carl Geiger, Christian Kanzow: Theorie und Numerik restringierter Optimierungsaufgaben. Springer 2002.		
Responsible Persons	Andreas Prohl		

Course Title:	Software Obfuscation: Mixed Boolean-Arithmetic Expressions		
Specialisation	Algebra		
Workload **- Time in Class** **- Self-Study**	Workload: 150 h	Time in Class: 45 h	Self-Study: 105 h
Frequency	not regularly		

Language of Instruction	German or English
Forms of Teaching and Learning	Lecture 2 SWS + Exercise class 1 SWS
Content	• What is software obfuscation and what is it used for? What techniques are there, and why is deobfuscation so difficult? What does a reverse engineer do? Introductory examples. • Mathematical foundations: ideals in $\mathbb{Z}$, greatest common divisor, Euclidean algorithm, time complexity estimates, rings and fields, computations in residue class rings, permutations, matrices and determinants, linear algebra over rings. • Boolean algebras and Boolean functions. • Fundamentals of mixed Boolean-arithmetic expressions (MBA). • Obfuscation using MBAs and permutation polynomials. • Deobfuscation using MBAs; analysis and comparison of state-of-the-art tools and their weaknesses. • Deobfuscation using program synthesis.
Special Objectives	The students are familiar with initial techniques in the field of software obfuscation and deobfuscation and understand the mathematical results required for this. They are able to apply these confidently.
Literature	**Possible References :** • Yongxin Zhou, Andrew Main, Yuxin Gu, Harrison Johnson. Information Hiding in Software with Mixed Boolean-Arithmetic Transforms. In: International Workshop on Information Security Applications (WISA). Springer, 2007, pp. 6175. • Bernhard Reichenwallner, Peter Meerwald-Stadler. Ecient Deobfuscation of Linear Mixed Boolean-Arithmetic Expressions. In: Proceedings of the 15th ACM Workshop on Articial Intelligence and Security (AISec 2022). ACM, 2022, pp. 119130.
Responsible Persons	Thomas Markwig

Course Title:	Topology		
Specialisation	Geometry		
Workload - Time in Class - Self-Study	Workload: 180 h	Time in Class: 60 h	Self-Study: 120 h
Frequency	not regularly		
Language of Instruction	German		
Forms of Teaching and Learning	Lecture 2 SWS + Exercise class 2 SWS		

Content	• Review of metric spaces: closed sets, environment, continuity, complete metric spaces, compactness in metric spaces metric spaces. • Set-theoretic topology: topological spaces, continuity convergence, compactness, separation axioms. • Spaces of continuous functions: Urysohn's lemma and applications, Stone-Cech compactification, the theorem of Stone-Weierstraß, notions of convergence in functions, compactness in spaces of functions. • Baire's spaces and application of Baire's theory: Baire's function classes, existence theorems. • Outlook on algebraic topology.
Special Objectives	Students have familiarised themselves with the central concepts, results and methods of set-theoretical topology and have understood that this theory can be used to describe many phenomena in different areas of mathematics. In this way, they link their knowledge of very different areas of mathematics.
Literature	**Possible References :** • Felix Hausdorff: Grundzüge der Mengenlehre. Von Veit & Comp. 1914. • Boto von Querenburg: Mengentheoretische Topologie. Springer 2001. • Volker Runde: A Taste of Topology. Springer 2005.
Responsible Persons	Rainer Nagel

Course Title:	Calculus of Variations		
Specialisation	Analysis		
Workload - Time in Class - Self-Study	Workload: 150 h	Time in Class: 45 h	Self-Study: 105 h
Frequency	not regularly		
Language of Instruction	German or English		
Forms of Teaching and Learning	Lecture 2 SWS + Exercise class 1 SWS		
Content	• Direct method of calculus of variations. • Euler-Lagrange equations. • Palais-Smale condition. • Mountain-Pass Lemma according to Ambrosetti-Rabinowitz.		
Special Objectives	In the first part of the course, students have learnt the direct method of calculus of variations, which is primarily used to prove the existence of weak solutions of partial differential equations, but also has applications in e.g. differential geometry. They have also acquired the necessary basics from functional analysis and partial differential equations and can also use these in a different context, e.g. geometric analysis. In the second part of the course, students learnt about a so-called mountain-pass lemma. With its help, they can analyse non-uniqueness in the existence of solutions of partial differential equations.		

Literature	**Possible References :** • Michael Struwe: Variational Methods, Springer 2008. • David Gilbarg, Neil S. Trudinger: Elliptic Partial Differential Equations of Second Order, Springer 1998. • Walter Rudin: Functional Analysis, Mc Graw Hill Education 1991.
Responsible Persons	Reiner Schätzle

Course Title:	Probability Theory		
Specialisation	Stochastics		
Workload - Time in Class - Self-Study	Workload: 270 h	Time in Class: 90 h	Self-Study: 180 h
Frequency	regularly in Winter Semester		
Language of Instruction	German		
Forms of Teaching and Learning	Lecture 4 SWS + Exercise class 2 SWS		
Content	• Characteristic functions and additions to the central limit theorem. • Conditional expectations and further measure-theoretic foundations. • Markov chains and martingales in discrete time, classification, asymptotic behaviour, stopping times, stationarity, ergodicity. • Introduction to processes in contiuous time like Poisson processes and Brownian motion.		
Special Objectives	The students got to know the central terms results and methods of probability theory. They can model, analyse and interprete stochastic dependency structures of random quantities in a measure theoretically founded manner. The students are capable of naming and proving the central results of the lecture as well as assessing and explaining the presented connections.		
Literature	**Possible References :** • Heinz Bauer: Wahrscheinlichkeitstheorie und Grundzüge der Maßtheorie. De Gruyter 2010. • Richard Durrett: Probability, Theory and Examples. Cambridge University Press 2010. • Hans-Otto Georgii: Stochastik. De Gruyter 2009. • Jean Jacod, Philip E. Protter: Probability essentials. Springer 2004. • Olav Kallenberg. Foundations of Modern Probability. Springer 2002. • Achim Klenke: Wahrscheinlichkeitstheorie. Springer 2013. • David Meintrup, Stefan Schäffler: Stochastik. Springer 2005. • Albert N. Shiryaev: Probability-1. Springer 2016.		
Responsible Persons	Martin Möhle, Martin Zerner		

<table>
<tr><td>Course Title:</td><td colspan="3">Number Theory and Cryptography</td></tr>
<tr><td>Specialisation</td><td colspan="3">Algebra</td></tr>
<tr><td>Workload
- Time in Class
- Self-Study</td><td>Workload:
270 h</td><td>Time in Class:
90 h</td><td>Self-Study:
180 h</td></tr>
<tr><td>Frequency</td><td colspan="3">not regularly</td></tr>
<tr><td>Language of Instruction</td><td colspan="3">German or English</td></tr>
<tr><td>Forms of Teaching and Learning</td><td colspan="3">Lecture 4 SWS + Exercise class 2 SWS</td></tr>
<tr><td>Content</td><td colspan="3">RSA cryptosystem, primality tests, AKS algorithm.
Factorisation methods, number field sieve.
Quadratic reciprocity in cryptography.
Evaluation of the discrete logarithm.
Dynamical systems and Pollard’s rho algorithm.
Elliptic curve cryptography.
Lattices and post-quantum cryptography.
Zero-knowledge proofs, digital signatures and hash functions.</td></tr>
<tr><td>Special Objectives</td><td colspan="3">The students know the basic concepts of elementary number theory and their applications in cryptography. They have deepened and extended their knowledge about neighbouring disciplines: They encounter methods of the theory of dynamical systems and become acquainted with elliptic curves over finite fields. They understand how fundamental cryptographic protocolls are working. Through studying many open problems of crytography, whose solutions may suprisingly come from most distinct branches of mathematics, the students learn to think critically.</td></tr>
<tr><td>Literature</td><td colspan="3">Possible References :
Jeffrey Hoffstein, Jill Pipher, Joseph H. Silverman: An introduction to mathematical cryptography. Springer 2008.
Stefan Müller-Stach, Jens Piontkowski: Elementare und algebraische Zahlentheorie. Vieweg+Teubner 2011.
Joseph H. Silverman, John T. Tate: Rational points on elliptic curves. Springer 1992.
Nigel Smart: Cryptography: An introduction. McGraw-Hill 2003. (online version: https://www.cs.bris.ac.uk/~nigel/Crypto_Book/).
Lawrence C. Washington: Elliptic curves: Number theory and cryptography. Chaman & Hall/CRC 2008.</td></tr>
<tr><td>Responsible Persons</td><td colspan="3">Elena Klimenko, Thomas Markwig</td></tr>
</table>