Studies Plan of the Master's Program of Mathematics

July 27, 2017

1 Qualification Objectives

Education within the Master's Program of Mathematics is aimed at preparing students for professional activity in financial sector (in particular at banks, insurance companies, and consulting companies), industry (in particular in the area of simulation or interpretation of simulation results and in the area of software production for various needs), as well as for a scientific career (doctorate) in mathematics, engineering and natural sciences or economics. Research-based education is designed to prepare graduates for life-long learning.

Scientific Core Competencies:

Graduates possess extended and in-depth knowledge in mathematics and, if applicable, in a complementary subject (Ergänzungsfach) of their choice. They are able to analyze and explain current, complex issues in these areas. They are familiar with the main mathematical disciplines (areas), their methodological approaches, and connections between them. Graduates are able to define, describe, and interpret concepts and terminologies in chosen areas, present the state of the art in research and to further develop certain aspects of these areas.

Transferable Skills:

Graduates can analyze topics from various perspectives. They can select and combine different approaches for research-relevant topics. They can transfer and apply these approaches to specific problems. They can study complex problems using various classical and contemporary methods. Doing this, they can evaluate the difficulty level and find methods and solutions improving previously known results. They are in a position to make critical and scientifically based decisions. Scientific knowledge is used across disciplines taking into account social, scientific, and ethical findings. Graduates develop innovative ideas and can implement them. They can pursue these approaches independently or in international teams. They are able to explain and discuss their decisions. They can

also exchange opinions on their topic of research with specialists in the area. They are in a position to independently interpret, verify, and illustrate the findings obtained. In particular, they can easily handle electronic media. Graduates are in the position to implement strategies for perseverance in a life-long learning.

Learning Outcomes:

Graduates can name, explain, and independently apply specialized mathematical methods. They have an in-depth understanding of mathematical methods from at least two of the four areas of *Algebra und Geometrie* (algebra and geometry), *Analysis* (analysis), *Angewandte und Numerische Mathematik* (applied and numerical mathematics), and *Stochastik* (probability theory).

Depending on the subject, graduates have vast knowledge of special mathematical models and methods. This enables them to analyze complex and innovative problems in the respective area and to assess the results.

2 Organization of Studies

The study program is divided into subjects, the subjects are divided into modules, and the modules are divided into courses, with most modules consisting of a lecture (with or without exercise) or a seminar. A successful completion of each module is typically assessed in a written exam, an oral exam, or a presentation. The average work amount is measured in credits. Generally, modules are graded. Exceptions are e.g. seminar modules that may only be passed or failed. The master's thesis consists of a module of its own with 30 credits. In total, 120 credits have to be acquired within the Master's Program. These credits can be distributed roughly uniformly over four semesters.

3 Subjects, Areas, and Modules

The modules offered in the subjects are assigned to one of the four **mathematical areas** *Algebra und Geometrie* (algebra and geometry), *Analysis* (analysis), *Angewandte und Numerische Mathematik* (applied and numerical mathematics), and *Stochastik* (probability theory). No specific module is a part of a requirement for the Master degree. However, in subject 1 "Mathematische Methoden 1" (mathematical methods 1), 24 credits have to be acquired in one of the four mathematical areas and in subject 2 "Mathematische Methoden 2" (mathematical methods 2), 16 credits have to be acquired in a second of the four areas. At least one of the areas chosen in these subjects must be *Algebra und Geometrie* (algebra and geometry) or *Analysis* (analysis). As for the rest, only lecture modules and no seminars are permitted in both subjects.

In subject 3 “Ergänzungsfach” (complementary subject), modules in the total amount of 16 to 24 credits have to be aquired. These modules have to be chosen either in one of the two mathematical areas not chosen in subject 1 and subject 2 or in one of the subjects of *Informatik* (informatics), *Physik* (physics), *Wirtschaftswissenschaften* (economics), *Maschinenbau* (mechanical engineering) or *Elektrotechnik* (electrical engineering). If the modules are chosen from one of the mathematical areas, no seminars are permitted. The modules from informatics, physics, economics, mechanical engineering, or electrical engineering and information technology are offered by the respective Departments of Informatics, Physics, Economics, Mechanical Engineering or Electrical Engineering and Information Technology. It is possible to choose modules from the master’s program and the advanced bachelor’s program of the respective departments. In some modules registration for exams is subject to certain conditions which are specified in the module manual. It is strongly recommended to discuss the planned course of studies in the complementary subject with the departmental advisor, if no mathematical area is chosen as a complementary subject. The modules permitted are listed in the module manual, others may be permitted by the examination committee. Other subjects may also be approved by the examination committee.

In subject 4 “Mathematisches Seminar” (mathematical seminar), two seminars of 3 credits each are required to obtain the necessary 6 credits as ungraded coursework.

In subject 5 “Mathematische Vertiefung” (mathematical specialization), modules in the amount of 14 to 22 credits have to be taken. The modules permitted in the above four mathematical areas are listed in the module manual. At most one ungraded seminar (with 3 credits) may be used in this subject.

The modules taken in the subjects of “Ergänzungsfach” (complementary subject) and “Mathematische Vertiefung” (mathematical specialization) must total in at least 38 credits.

Subject 6 “Überfachliche Qualifikation” (transferable skills) contribute to 6 credits (see Section 6). The attended courses may be graded or not graded. In any case, the grade will not be considered when calculating the total grade for the master degree.

Mathematische Methoden 1 (mathematical methods 1) (24 credits)	Mathematische Methoden 2 (mathematical methods 2) (16 credits)
Ergänzungsfach (complementary subject) (16 – 24 credits)	Mathematische Vertiefung (mathematical specialization) (14 – 22 credits)
Ergänzungsfach (complementary subject) and Mathematische Vertiefung (mathematical specialization) together have to result in 38 credits at least.	

Mathematisches Seminar (mathematical seminar) (6 credits)	Überfachliche Qualifikation (transferable skills) (6 credits)
Master's thesis (30 credits)	

4 Introductory Modules in the Mathematical Areas

In the subjects, those modules can be selected, that are particularly suited for introduction to the mathematical areas covered by the master's program. The following modules are offered regularly, i.e. at least every second year, and correspond to 8 credits (if not stated otherwise). The following abbreviations are used: SWS = Semesterwochenstunde in Vorlesung + Übung (hour per week per semester spent for lectures and exercises), Ws = Wintersemester (winter semester), Ss = Sommersemester (summer semester).

- **Algebra und Geometrie (algebra and geometry)**
  - Algebra (algebra) (4+2 SWS, Ws)
  - Differentialgeometrie (differential geometry) (4+2 SWS, Ss)
  - Geometrische Gruppentheorie (geometrical group theory) (4+2 SWS, Ss)

These courses are offered annually and are recommended for our students in the bachelor's program. If these courses have not been attended within the bachelor's program, we recommend them as important introductory modules for the area of Algebra und Geometrie (algebra and geometry). If these modules have been attended within the bachelor's program already, we recommend the following modules.

- Algebraische Zahlentheorie (algebraic number theory) (4+2 SWS) (prerequisite: Algebra (algebra))
- Algebraische Geometrie (algebraic geometry) (4+2 SWS) (prerequisite: Algebra (algebra))
- Globale Differentialgeometrie (global differential geometry) (4+2 SWS) (prerequisite: Differentialgeometrie (differential geometry))
- Algebraische Topologie (algebraic topology) (4+2 SWS)
- Stochastische Geometrie (stochastic geometry) (4+2 SWS, Ss) (prerequisite: Räumliche Stochastik (spatial stochastics))[1]

- **Analysis (analysis)**
  - Funktionalanalysis (functional analysis) (4+2 SWS, Ws)

[1] This module can be assigned to the areas of stochastics or algebra and geometry.

- Spektraltheorie (spectral theory) (4+2 SWS, Ss)
- Klassische Methoden für partielle Differentialgleichungen (classical methods for partial differential equations) (4+2 SWS, Ws)
- Rand- und Eigenwertprobleme (boundary value and eigenvalue problems) (4+2 SWS, Ss)

These courses are offered annually and recommended to our students in the bachelor's program. If they have not been attended within the bachelor's program, we recommend them as important introductory modules for the area of Analysis (analysis). If these modules have been attended within the bachelor's program already, we recommend the following modules.

- Evolutionsgleichungen (evolution equations) (4+2 SWS) (prerequisite : Funktionalanalysis (functional analysis))
- Fourieranalysis (Fourier analysis) (4+2 SWS) (prerequisite : Funktionalanalysis (functional analysis))
- Integralgleichungen (integral equations) (4+2 SWS) (prerequisite : Funktionalanalysis (functional analysis))
- Geometrische Analysis (geometrical analysis) (4+2 SWS) (prerequisite : Klassische Methoden für partielle Differentialgleichungen (classical methods for partial differential equations))
- Randwertprobleme für nichtlineare Differentialgleichungen (boundary value problems for non-linear differential equations) (4+2 SWS) (prerequisite : Rand- und Eigenwertprobleme (boundary value and eigenvalue problems))

- **Angewandte und Numerische Mathematik (applied and numerical mathematics)**
  - Numerische Methoden für Differentialgleichungen (numerical methods for differential equations) (4+2 SWS, Ws)
  - Einführung in das Wissenschaftliche Rechnen (introduction to scientific computing) (3+3 SWS, Ss)
  - Inverse Probleme (inverse problems) (4+2 SWS, Ws)[2]

These courses are offered annually and recommended to our students in the bachelor's program. If they have not been attended within the bachelor's program, we recommend them as important introductory modules for the area of Angewandte und Numerische Mathematik (applied and numerical mathematics). If these modules have been attended within the bachelor's program already, we recommend the following modules. (Sometimes, additional analysis knowledge is required, which is specified in more detail in the corresponding module descriptions.)

[2] This module can be assigned to the areas of applied and numerical mathematics or analysis.

- Finite Elemente Methoden (finite element methods) (4+2 SWS, Ws) (prerequisite : Numerische Methoden für Differentialgleichungen (numerical methods for differential equations))
- Numerische Optimierungsmethoden (numerical optimization methods) (4+2 SWS) (prerequisite : Optimierungstheorie aus dem Bachelorstudium (optimization theory of the bachelor's program))
- Numerische Methoden für zeitabhängige partielle Differentialgleichungen (numerical methods for time-dependent partial differential equations) (4+2 SWS) (prerequisite : Numerische Methoden für Differentialgleichungen (numerical methods for differential equations))
- Numerische Methoden in der Finanzmathematik (numerical methods in financial mathematics) (4+2 SWS) (prerequisite : Numerische Methoden für Differentialgleichungen (numerical methods for differential equations))
- Spezielle Themen der Numerischen Linearen Algebra (special topics of numerical linear algebra) (4+2 SWS, Ss, is offered every two years)

- **Stochastik (probability theory)**
  - Finanzmathematik in diskreter Zeit (financial mathematics in discrete time) (4+2 SWS, Ws)
  - Finanzmathematik in stetiger Zeit (financial mathematics in continuous time) (4+2 SWS, Ss)
  - Asymptotische Stochastik (asymptotic stochastics) (4+2 SWS, Ws)
  - Räumliche Stochastik (spatial stochastics) (4+2 SWS, Ws)
  - Stochastische Geometrie (stochastic geometry) (4+2 SWS, Ss)[3] (prerequisite : Räumliche Stochastik (spatial stochastics))
  - Generalisierte Regressionsmodelle (generalized regression models) (2+1 SWS, 4 credits, Ss)
  - Zeitreihenanalyse (time series analysis) (2+1 SWS, 4 credits, Ss)

These courses are offered annually and recommended to our students in the bachelor's program. If they have not been attended within the bachelor's program, we recommend them as important introductory modules for the area of Probability Theory. The following modules are also recommended.

- Mathematische Statistik (mathematical statistics) (2+1 SWS, 4 credits)
- Nichtparametrische Statistik (non-parametric statistics) (2+1 SWS, 4 credits)
- Der Poisson-Prozess (Poisson's process) (3+1 SWS, 6 credits)
- Brownsche Bewegung (Brownian motion) (2+1 SWS, 4 credits)

[3] This module can be assigned to the area of stochastics or the area of algebra and geometry.

- Vorhersagen: Theorie und Praxis (predictions: theory and practice) (part 1: 2 SWS, 3 credits; part 2: 2+2 SWS, 5 credits)

5 Advanced Modules in the Mathematical Areas

The module manual lists a number of additional modules that are offered irregularly. These modules are based on the modules listed in Section 4 and deepen the knowledge in the respective areas. Together with seminars, these modules enable students to write a master's thesis in a special area.

6 Transferable Skills

Transferable skills also are to be acquired during the studies by taking mathematics course, seminars, doing research, and writing a thesis. In addition, transferable skills are imparted by cross-disciplinary courses on social topics, complementary scientific courses to convey use of scientific knowledge in daily working life, specific trainings of soft skills, and language trainings in the scientific context.

The transferable skills acquired while covering mathematics curriculum of the Master's Program include:

- **Basic Competencies (soft skills)**
  1. Team work, social communication (work in small groups, joint homework, and wrap-up of the lecture contents)
  2. Preparation of presentations and presentation techniques (seminar presentations)
  3. Logical and systematic argumentation and writing (in the tutorial or seminar, when preparing presentations, and doing the homework)
  4. English as a scientific language

- **Orientation Knowledge**
  1. Interdisciplinary knowledge on the application subject
  2. Media, technology, and innovation

In addition, transferable skills in the amount of at least 6 credits within special modules are required. Within the module Überfachliche Qualifikationen (transferable skills), courses of the House of Competence (HoC), of the Language Center, or of the Center for Applied Cultural Sciences (ZAK) may be attended. Every semester, the course programs are updated. The contents are outlined in detail in the descriptions of the courses on the websites of HoC (https://www.hoc.kit.edu/index.php, in German only), ZAK (http://www.zak.kit.edu/english/), and the Language Center

(https://www.spz.kit.edu/, in German only). In the module manual integrated here, the individual courses are not listed. Instead, an overview of the electives is given.

7 Exemplary Courses of Studies

In the following examples, modules from the four mathematical areas are chosen for the Ergänzungsfach (complementary subject). As credits in the range from 16 to 24 are to be acquired in the complementary subject, selection is quite easy.

Example 1: start in the summer semester

Semester 1: 30 credits, 4 examinations

- Subject 1 (Analysis, analysis): Spektraltheorie (spectral theory) 8 credits
- Subject 2 (Stochastik, stochastics): Zeitreihenanalyse (time series analysis) 4 credits, Generalisierte Regressionsmodelle (generalized regression models) 4 credits
- Subject 3 (Algebra und Geometrie, algebra and geometry): Geometrische Gruppentheorie (geometrical group theory) 8 credits
- Subject Überfachliche Qualifikation (transferable skills) 3 credits
- Subject Mathematisches Seminar (mathematical seminar) 3 credits

Semester 2: 32 credits, 4 examinations

- Subject 1 (Analysis, analysis): Funktionalanalysis (functional analysis) 8 credits, Klassische Methoden für Partielle Differentialgleichungen (classical methods for partial differential equations) 8 credits
- Subject 2 (Stochastik, stochastics): Asymptotische Stochastik (asymptotic stochastics) 8 credits
- Subject 3 (Algebra und Geometrie, algebra and geometry): Geometrische Gruppentheorie 2 (geometrical group theory 2) 8 credits or Algebraische Topologie (algebraic topology) 8 credits

Semester 3: 28 credits, 3 examinations

- Subject Mathematische Vertiefung (mathematical specialization): Finanzmathematik in stetiger Zeit (financial mathematics in continuous time) 8 credits, Einführung in das Wissenschaftliche Rechnen (introduction to scientific computing) or Spezielle Themen der Numerischen Linearen Algebra (special topics of numerical linear algebra) with 8 credits each, special lecture with 6 credits, such as Perkolation (percolation) or Der Poissonprozess (Poisson's process) or Numerische Verfahren für Maxwellgleichungen (numerical methods for Maxwell equations) or Geometrische Numerische Integration (geometrical numerical integration) or Steuerungstheorie (control theory)
- Subject Überfachliche Qualifikation (transferable skills) 3 credits
- Subject Mathematisches Seminar (mathematical seminar) 3 credits

Semester 4: 30 credits

- Master's thesis

Example 2: start in the summer semester

Semester 1: 30 credits, 4 examinations

- Subject 1 (Stochastik, stochastics): Finanzmathematik in stetiger Zeit (financial mathematics in continuous time) 8 credits, Zeitreihenanalyse (time series analysis) 4 credits, Generalisierte Regressionsmodelle (generalized regression models) 4 credits
- Subject 2 (Algebra und Geometrie, algebra and geometry): Geometrische Gruppentheorie (geometrical group theory) 8 credits
- Subject Überfachliche Qualifikation (transferable skills) 3 credits
- Subject Mathematisches Seminar (mathematical seminar) 3 credits

Semester 2: 30 credits, 3 examinations

- Subject 1 (Stochastik, stochastics): Räumliche Stochastik (spatial stochastics) 8 credits
- Subject 2 (Algebra und Geometrie, algebra and geometry): Algebraische Topologie (algebraic topology) 8 credits
- Subject 3 (Angewandte und Numerische Mathematik, applied and numerical mathematics): Numerische Methoden für Differentialgleichungen (numerical methods for differential equations) 8 credits
- Subject Überfachliche Qualifikation (transferable skills) 3 credits
- Subject Mathematisches Seminar (mathematical seminar) 3 credits

Semester 3: 30 credits, 4 examinations

- Subject 3 (Angewandte und Numerische Mathematik, applied and numerical mathematics): Einführung in das Wissenschaftliche Rechnen (introduction to scientific computing) 8 credits

- Subject Mathematische Vertiefung (mathematical specialization): Stochastische Geometrie (stochastic geometry) 8 credits, Algebraische Topologie 2 (algebraic topology 2) 8 credits, special lecture 6 credits (or two seminars or one seminar and a special lecture with 3 credits)

Semester 4: 30 credits

- Master's thesis

Example 3: start in the winter semester

Semester 1: 30 credits, 3 examinations

- Subject 1 (Algebra und Geometrie, algebra and geometry): Algebra (algebra) 8 credits, another module (Algebra und Geometrie, algebra and geometry) 8 credits
- Subject 2 (Analysis, analysis): Funktionalanalysis (functional analysis) 8 credits
- Subject Überfachliche Qualifikation (transferable skills) 3 credits
- Subject Mathematisches Seminar (mathematical seminar) 3 credits

Semester 2: 30 credits, 3 examinations

- Subject 1 (Algebra und Geometrie, algebra and geometry): Geometrische Gruppentheorie (geometrical group theory) 8 credits
- Subject 2 (Analysis, analysis): Rand- und Eigenwertprobleme (boundary value and eigenvalue problems) 8 credits
- Subject Mathematische Vertiefung (mathematical specialization): Geometrie der Schemata (geometry of schemes) 8 credits
- Subject Überfachliche Qualifikation (transferable skills) 3 credits
- Subject Mathematisches Seminar (mathematical seminar) 3 credits

Semester 3: 30 credits, 3 examinations

- Subject Mathematische Vertiefung (mathematical specialization): Geometrische Gruppentheorie 2 (geometrical group theory 2) 8 credits
- Subject 3 (Stochastik, stochastics): Asymptotische Stochastik (asymptotic stochastics) 8 credits, Räumliche Stochastik (spatial stochastics) 8 credits, Der Poissonprozess (Poisson's process) 6 credits (or another course with 6 credits)

Semester 4: 30 credits

- Master's thesis

Example 4: start in the winter semester

Semester 1: 30 credits, 3 examinations

- Subject 1 (Analysis, analysis): Funktionalanalysis (functional analysis) 8 credits

- Subject 2 (Stochastik, stochastics): Räumliche Stochastik (spatial stochastics) 8 credits or Finanzmathematik in diskreter Zeit (financial mathematics in discrete time) 8 credits
- Subject 3 (Angewandte und Numerische Mathematik, applied and numerical mathematics): Numerische Methoden für Differentialgleichungen (numerical methods for differential equations) 8 credits
- Subject Überfachliche Qualifikation (transferable skills) 3 credits
- Subject Mathematisches Seminar (mathematical seminar) 3 credits

Semester 2: 30 credits, 3 examinations

- Subject 1 (Analysis, analysis): Spektraltheorie (spectral theory) 8 credits
- Subject 2 (Stochastik, stochastics): Stochastische Geometrie (stochastic geometry) 8 credits or Finanzmathematik in stetiger Zeit (financial mathematics in continuous time) 8 credits
- Subject 3 (Angewandte und Numerische Mathematik, applied and numerical mathematics): Einführung in das Wissenschaftliche Rechnen (introduction to scientific computing) or Spezielle Themen der Numerischen Linearen Algebra (special topics of numerical linear algebra) 8 credits each
- Subject Überfachliche Qualifikation (transferable skills) 3 credits
- Subject Mathematisches Seminar (mathematical seminar) 3 credits

Semester 3: 30 credits, 4 or 3 examinations

- Subject 1 (Analysis, analysis): Klassische Methoden für Partielle Differentialgleichungen (classical methods for partial differential equations) 8 credits
- Subject 3 (Angewandte und Numerische Mathematik, applied and numerical mathematics): Finite Elemente Methoden (finite element methods) 8 credits
- Subject Mathematische Vertiefung (mathematical specialization): module from algebra and geometry with 8 credits or asymptotic stochastics 8 credits
- Subject Mathematische Vertiefung (mathematical specialization): lecture module with 6 credits or two seminars with a total of 6 credits

Semester 4: 30 credits

- Master's thesis