TECHNISCHE UNIVERSITÄT WIEN

Bachelor

Master

Doktorat

Universitäts-lehrgang

Studienplan (Curriculum)
für das

## Masterstudium

# Mathematical Modelling in Engineering: Theory, Numerics, Applications
# E 066 393

Technische Universität Wien
Beschluss des Senats der Technischen Universität Wien
mit Wirksamkeit 22. Juni 2020

Gültig ab 1. Oktober 2020

# Inhaltsverzeichnis

# 1. Grundlage und Geltungsbereich (Basis and Scope)

Der vorliegende Studienplan definiert und regelt den an der Technischen Universität Wien angebotenen Teil des naturwissenschaftlichen Masterstudiums „Mathematical Modelling in Engineering: Theory, Numerics, Applications“. Dieser basiert auf dem Universitätsgesetz 2002 BGBl. I Nr. 120/2002 (UG) und den Studienrechtlichen Bestimmungen der Satzungen der Technischen Universität Wien in der jeweils geltenden Fassung. Die Struktur und Ausgestaltung dieses *englischsprachigen* Studiums orientieren sich am Qualifikationsprofil gemäß Abschnitt 2; die diesen gesetzlichen Rahmenbedingungen für Studien an der Technischen Universität Wien entsprechenden Abschnitte 7–12 sind in deutscher Sprache ausgeführt, während der Rest des Studienplans in englischer Sprache abgefasst ist. Für Lehrveranstaltungen und Prüfungen, die an den Partneruniversitäten – Università degli Studi dell'Aquila (L'Aquila) in Italien und Universitat Autònoma de Barcelona (UAB) in Spanien – abgehalten werden, gelten deren Vorschriften.

The present curriculum defines and regulates the part of the natural science master program „Mathematical Modelling in Engineering: Theory, Numerics, Applications“ offered at Technische Universität Wien. It is based on the University Law BGBl. I Nr. 120/2002 (UG) and the regulations of the statutes of Technische Universität Wien as amended; the relevant sections 7–12 containing these legal conditions for studies at Technische Universität Wien are executed in German while the rest of the curriculum is written in English. For the courses and exams held at the partner universities – Università degli Studi dell'Aquila (L'Aquila), Italy, and Universitat Autònoma de Barcelona (UAB), Spanien – their rules apply. Structure and design of this *English* curriculum are based on the qualification profile according to section 2.

# 2. Qualifikationsprofil (Qualification Profile)

## 2.1. Introduction

*Mathematical modeling* refers to the use of mathematics and related computational tools to bring real-world, challenging and important socio-economic and industrial problems into a form simple enough so that a good solution can be found in reasonable time, while keeping the relevant features of the problem. Constructing models requires advanced knowledge of mathematical theory, methods for solving problems which are effective and efficient, computational tools at hand to be used, sound knowledge of the field of application, and communicative skills to understand the important elements from experts in that field. Our master curriculum tries to put together all these elements to produce professionals able to work in different relevant fields with the highest intellectual level and state-of-the-art tools.

Effective modeling and simulation is an art that requires a lot of practice, so that problem solving, project development and teamwork are aspects that should be highlighted in any training program. On the other hand, the abstraction behind the specific application is necessary to realize that the same base tools can be applied, with the needed changes, to very different situations in various fields of engineering.

This proposed joint master curriculum involves three European universities: Università degli Studi dell'Aquila (L'Aquila), Technische Universiät Wien (TU Wien), and Universitat Autònoma de Barcelona (UAB), Catalonia, Spain. All the specializations offered, which reflect fields of excellence of the participating centers, are related to mathematical modeling with applications to engineering. The graduate completing the proposed program is expected to feature the main qualities required nowadays from a mathematical modeler in engineering, namely being capable of developing models and promoting innovative processes.

This master curriculum is more wide-ranging when compared to traditional master programs in *Technical Mathematics*, since it covers several methodological areas of mathematics that are shared by very diverse fields of applications in engineering, with a special focus on modern applications. Moreover, it addresses more directly to the solution of problems in engineering. The object of the course in general is to encourage open-minded flexibility in the approach to problem solving so as to enable the graduate to deal with problems which may be quite different to those encountered specifically during the course of study.

This master curriculum offers an actual integration of the program: it is not just a multiple degree program based on the local programs of the three partners. The diploma awarded is a joint one and the mobility is designed to contribute to the consistency of the curriculum instead of disturbing it. The use of the English language – the language common to science and technology – in all activities throughout the whole program contributes to the rapid integration of students among them and to that of students and teachers, without forgetting the important aspect of immersion in the local cultures.

The master program „Mathematical Modelling in Engineering: Theory, Numerics, Applications“ provides in-depth, scientifically and methodically high-quality education aiming at lasting knowledge, which qualifies the graduates both for further qualification, especially in the context of a relevant doctoral degree program and for employment in, for example, the following fields of activity, and it makes them internationally competitive:

- Engineering companies involved in both consultant as well as research and development activities;
- Companies or public bodies for the management of services;
- Manufacturing industries that produce and integrate complex systems;
- Companies that produce software dedicated to modeling and simulation;
- Institutes and research laboratories in the field of engineering, applied mathematics, math finance and applied physics.

## 2.2. Conveyed qualifications

Due to the professional requirements, the master curriculum „Mathematical Modelling in Engineering“ conveys qualifications in the following categories.

### 2.2.1. Professional and methodical competences

Due to the richness of the mathematical applications and the diversity of the need for mathematical skills, in addition to sound basic mathematical knowledge, a focused education is an essential tool to specialize deeply on a specific area of application or to a specific methodological branch.

The curriculum provides four possible options:

- Advanced modelling and numerics for applied PDEs (TU Wien),
- Stochastic modelling and optimisation (UAB);
- Mathematical models in social sciences (L'Aquila);
- Mathematical modeling and optimization (L'Aquila).

Depending on the chosen focus, the study of Mathematical Modelling provides in-depth knowledge in several of the following areas:

- Functional analysis,
- Advanced analysis,
- Control systems,
- Dynamical systems and bifurcation theory,
- Partial differential equations,
- Numerical methods for ODEs and PDEs,
- Optimisation,
- Probability and stochastic processes,
- High performance computing,
- Mathematical models for collective behaviour,
- Fluid dynamics,
- Biomathematics,
- Systems biology,
- Modelling and control of networked distributed systems.

### 2.2.2. Cognitive and practical competences

The study conveys essential mathematical ways of thinking and working. These include in particular:

- recognition of structures, abstraction ability;
- logical and algorithmic procedure;
- ability to work independently on new subject-relevant questions, methods and (especially English-language) scientific literature;

- ability to document solutions and critically evaluate them;
- communication and presentation;
- first insights into the science business.

As the whole program is taught in English and there is a compulsory mobility, students also acquire foreign language skills: predominantly in English, but also in Italian, German and in some cases Catalan.

#### 2.2.3. Social skills and self-competences

Important competences are:

- scientific reasoning;
- adaptability and willingness to critically and intensively deal with other sciences, which often form the context of a project;
- presentation of results and hypotheses;
- accuracy and endurance.

# 3. Dauer und Umfang (Duration and Scope)

The total work load for the master curriculum „Mathematical Modelling in Engineering: Theory, Numerics, Applications“ is 120 ECTS-points[1]. For full time students, this corresponds to a foreseen study duration of 4 semesters.

# 4. Zulassung zum Masterstudium (Admission to the master program)

The admission to the master program „Mathematical Modelling in Engineering: Theory, Numerics, Applications“ requires the completion of a thematically relevant bachelor study at a recognized University or University of Applied Studies. This qualification has to be verified by the Università degli Studi dell'Aquila.

Thematically relevant bachelor studies at Technische Universität Wien, for example, are the bachelor programs „Technical Mathematics“, „Statistics and Mathematics in Economics“, „Financial and Actuarial Mathematics“, „Technical Physics“, „Mechanical Engineering“, and „Electrical Engineering and Information Technology“ at Technische Universität Wien.

The master program has a limitation on the number of students that are admitted every year to the first semester. The applications of students that satisfy the formal

[1] ECTS (European Credit Transfer System) points are a measure for the standard amount of work of students, where one ECTS credit corresponds to the amount of work of 25 full hours of an „average student“. The standard amount of work of one academic year is normalized at 60 ECTS credits.

qualification for this master program are then subject to a selection procedure, based on one linear ranking of these applications. The three participating universities participate at this selection procedure at an equal footing.

Students can only register for this master program at TU Wien, if they are still keeping an active status of this very master program at the Università degli Studi dell'Aquila, where they passed the first semester.

# 5. Aufbau des Studiums (Structure of the study)

The contents and qualifications of this curriculum are conveyed in modules. A module is a teaching and learning unit, which is characterized by input and output qualifications, contents, teaching and learning forms, the standard work load as well as the grading system. Mastering a module is done in form of individual or multiple, thematically related courses. Thematically similar modules are combined into examination fields, whose name, size, and over-all grade are represented in the final grade report.

The master program „Mathematical Modelling in Engineering: Theory, Numerics, Applications“ consists of the following examination fields and the following modules.

## 5.1. Semester 1 (WS) at Università degli Studi dell'Aquila

| Module | ECTS |
|---|---|
| Functional analysis in applied mathematics and engineering | 8 |
| Dynamical systems and bifurcation theory | 6 |
| Applied partial differential equations | 6 |
| Control systems | 6 |
| Italian language and culture for foreigners (A1 level) | 4 |
| volume of semester 1 | 30 |

## 5.2. Semester 2 (SS) at Technische Universität Wien

| Module | ECTS |
|---|---|
| Computer programming | 5 |
| Numerics for differential equations | 15 |
| Elective course | 6 |
| German (A1 level) | 4 |
| volume of semester 2 | 30 |

Courses in the compulsory module „Computer programming“:

- Scientific programming in mathematics (VU: 3 ECTS)
- Programming with MATLAB (VU: 2 ECTS)

Courses in the compulsory module „Numerics for differential equations“:

- Numerics of differential equations (VO+UE: 8 ECTS)
- AKNUM Numerical methods for PDEs (VO+UE: 7 ECTS)

Courses in the compulsory module „German A1“ (VU: 4 ECTS):

- If students have already reached the A1-level in German, this module may be replaced by any courses of choice („Freie Wahlfächer“) in the amount of 4 ECTS.

As *elective course* one of the following items has to be chosen:

- Introduction to parallel computing (VU: 6 ECTS) This elective course is available only in German language.
- Stationary processes and time series analysis (VO+UE: 6 ECTS)
- AKNUM, AKOR Numerical optimisation (VO+UE: 6 ECTS)
- Basics of Parallel Computing (VU: 3 ECTS) + Energy-efficient Distributed Systems (VU: 3 ECTS)
- Iterative solution of large systems (VO+UE: 6 ECTS)

## 5.3. Semester 3 (WS) and 4 (SS) at Technische Universität Wien, Università degli Studi dell'Aquila, or Universitat Autònoma de Barcelona

The students have to choose one *Topical Focus* out of four options (in accordance with the capacity of the three participating universities). The Topical Focus determines the university and the choice of courses to be taken.

**Topical focus *Advanced Modelling and Numerics for Applied PDEs* (MN) at Technische Universität Wien**

| Module | ECTS |
|---|---|
| Modelling | 6 |
| Scientific computing | 12 |
| Elective courses | 12 |
| Diploma thesis with diploma exam | 30 |
| total volume of study (incl. semester 1+2) | 120 |

Courses in the compulsory module „modelling“:

- Modelling with PDEs (VO+UE: 6 ECTS)

Courses in the compulsory module „scientific computing“:

- Introduction to Python programming for geoscience (VU: 1.5 ECTS)
- Numerical simulation and scientific computing I (VO+UE or VU: 6 ECTS)
- High performance computing (VU: 4.5 ECTS)

*Elective courses* in the amount of 12 ECTS have to be chosen from the following list out of the three elective modules A, B, and C. Excess ECTS (beyond 4) from the German course in semester 2 may also be used here, with a maximum of 2 excess ECTS.

- Numerical methods in fluid dynamics (VO+UE: 5 ECTS)
- Finite element methods for multi-physics (VO+UE: 3+2 ECTS)
- Finite element methods for multi-physics I (VU: 4 ECTS)
- Calculating turbulent flows with CFD-codes (UE: 3 ECTS)
- Functional analysis 2 (VO+UE: 4.5+1.5 ECTS)
- Stochastic analysis in financial and actuarial mathematics 1 (VO+UE: 5+2 ECTS)
- Excess German (VU: up to 2 ECTS)

Only Finite element methods for multi-physics I VU or only Finite element methods for multi-physics VO and/or UE may be chosen.

### Topical focus *Stochastic Modelling and Optimisation* (SM) at Universitat Autònoma de Barcelona

| Module | ECTS |
|---|---|
| Probability and stochastic processes | 6 |
| Combinatorial optimisation | 6 |
| Workshop of mathematical modelling | 6 |
| Elective courses | 12 |
| Diploma thesis with diploma exam | 30 |
| overall volume of curriculum (incl. semester 1+2) | 120 |

As *elective courses*, two of the following items have to be chosen:

- Simulation of logistic systems (6 ECTS)
- Data visualization and modelling (6 ECTS)
- Parallel programming (6 ECTS)
- Research and innovation (6 ECTS)

### Topical focus *Mathematical models in social sciences* (SS) at the Università degli Studi dell'Aquila

| Module | ECTS |
|---|---|
| Advanced analysis 1 | 6 |
| Mathematical models for collective behaviour | 6 |
| Mathematical fluid dynamics | 6 |
| Elective courses | 12 |
| Diploma thesis with diploma exam | 30 |
| overall volume of curriculum (incl. semester 1+2) | 120 |

As *elective courses*, two of the following items have to be chosen:

- Biomathematics (6 ECTS)
- Systems biology (6 ECTS)
- Modelling seismic wave propagation (6 ECTS)
- Time series and prediction (6 ECTS)

**Topical focus *Mathematical modelling and optimisation* (MO) at the Università degli Studi dell'Aquila**

| Module | ECTS |
|---|---|
| Advanced analysis | 6 |
| Optimization in signal processing and wavelets | 6 |
| Optimisation models and algorithms | 6 |
| Process and operations scheduling | 6 |
| Modelling and control of networked distributed systems | 6 |
| Diploma thesis with diploma exam | 30 |
| overall volume of curriculum (incl. semester 1+2) | 120 |

**Subject areas at Technische Universität Wien** In the modules of the master curriculum „Mathematical Modelling in Engineering: Theory, Numerics, Applications" offered at the Technische Universität Wien the following subject areas are conveyed.

*Scientific programming in mathematics:* introductory knowledge of C++ as needed for the parallel numerical methods courses

*Programming with MATLAB:* MATLAB syntax (command- and object-oriented), graphical representations, toolboxes, selected problems from engineering and statistics

*Numerics of differential equations:* Knowledge of standard discretization methods for the approximation of solutions of ordinary differential equations; introduction to the discretization of partial differential equations

*Numerical methods of partial differential equations:* Knowledge of numerical standard models for partial differential equations. Finite element methods. Discontinuous Galerkin methods. Instationary PDEs

*Stationary processes and time series analysis:* Stationary processes, autocovariance function, spectral representation, linear filters, transfer function, AR/ARMA processes, forecasting, Wold representation, estimation

*Introduction to parallel computing:* Basic of parallel computing, parallel architectures, programming models, languages and interfaces, performance analysis and modeling, pitfalls, basic programming skills

*Numerical optimization:* Unconstrained optimization: gradient methods, classical Newton method, quasi-Newton method. Constrained optimization: trust region methods, linear programming, (sequential) quadratic programming

*Numerical simulation and scientific computing I:* Essential features of scientific computing: numerical methods for differential equations, selected programming languages, computer architectures, performance issues

*Modeling with partial differential equations:* Essential features of using partial differential equations for the modeling of technical and natural scientific problems

*Numerical methods in fluid dynamics:* Methods for convection-diffusion equations, projection methods for incompressible and compressible Navier-Stokes equations, treatment of complex geometries, turbulence modeling.

*Calculating turbulent flows with CFD-codes:* Application of commercial and open source CFD programs: calculation of (turbulent) flows, different turbulence models, verification by data from the literature.

*High performance computing:* current HPC architectures and communication networks, problems, algorithms and solutions; advanced MPI programming, tools, performance models, libraries

*Functional analysis 2:* Gelfand transformation, spectral theorem for bounded normal and in particular for unitary operators in Hilbert spaces, spectral theorem for unbounded selfadjoint operators on Hilbert spaces, strongly continuous semigroups, theorem of Hille-Yoshida

*Finite element methods for multi-physics:* Finite-Element method and aspects for computer implementation, computation of mechanical problems, coupled field problems (magnetic, mechanical and acoustic), optimization of modern mechatronic systems

*Introduction to Python programming:* Python overview, numerical packages, Iterators, Generators, Object oriented programming.

*Stochastic analysis in financial and actuarial mathematics 1:* Main features of stochastic analysis (Itô-integral w.r.t. Brownian motion)

*German A1:* Basic level of both written and spoken German (A1 level according to CEFR)

*Diploma thesis with diploma exam:* Writing of a scientific diploma thesis and defending it

# 6. Akademischer Grad (Academic degree)

Den Absolventinnen und Absolventen des Masterstudiums „Mathematical Modelling in Engineering: Theory, Numerics, Applications" wird der akademische Grad „Master of Science" – abgekürzt „MSc" – verliehen, und zwar als „Joint Degree" zwischen Università degli Studi dell'Aquila (L'Aquila), Universitat Autònoma de Barcelona und der Technischen Universität Wien. Die Aushändigung der Diplomurkunde erfolgt durch die Universität L'Aquila.

The graduates of the master program „Mathematical Modelling in Engineering: Theory, Numerics, Applications" will be awarded the academic degree „Master of Science" – abbreviated „MSc", as a „Joint Degree" between Università degli Studi dell'Aquila (L'Aquila), Universitat Autònoma de Barcelona and Technische Universität Wien. The diploma is awarded by the University of L'Aquila.

# 7. Lehrveranstaltungen

Die Stoffgebiete der Module werden durch Lehrveranstaltungen vermittelt. Die Lehrveranstaltungen der einzelnen Module sind im Anhang in den jeweiligen Modulbeschreibungen spezifiziert. Lehrveranstaltungen werden durch Prüfungen im Sinne des Universitätsgesetzes beurteilt. Die Arten der Lehrveranstaltungsbeurteilungen sind in der Prüfungsordnung (Abschnitt 8) festgelegt.

Jede Änderung der Lehrveranstaltungen der Module wird in der Evidenz der Module dokumentiert und ist mit Übergangsbestimmungen zu versehen. Jede Änderung wird in den Mitteilungsblättern der Technischen Universität Wien veröffentlicht. Die aktuell gültige Evidenz der Module liegt sodann in der Rechtsabteilung auf.

# 8. Prüfungsordnung

Den Abschluss des Masterstudiums bildet die Diplomprüfung. Sie beinhaltet

a. die erfolgreiche Absolvierung aller im Curriculum vorgeschriebenen Module, wobei ein Modul als positiv absolviert gilt, wenn die ihm zuzurechnenden Lehrveranstaltungen gemäß Modulbeschreibung positiv absolviert wurden,

b. die Abfassung einer positiv beurteilten Diplomarbeit und
c. eine kommissionelle Abschlussprüfung. Diese erfolgt mündlich vor einem Prüfungssenat gem. §12 und §19 Satzungsteil „Studienrechtliche Bestimmungen“ der Technischen Universität Wien und dient der Präsentation und Verteidigung der Diplomarbeit und dem Nachweis der Beherrschung des wissenschaftlichen Umfeldes. Dabei ist vor allem auf Verständnis und Überblickswissen Bedacht zu nehmen. Die Anmeldevoraussetzungen zur kommissionellen Abschlussprüfung gem. §18 Abs.1 Satzungsteil „Studienrechtliche Bestimmungen“ der Technischen Universität Wien sind erfüllt, wenn die Punkte a. und b. erbracht sind.

Das Abschlusszeugnis beinhaltet

a. als Prüfungsfächer die Module (wobei die beiden Module *Elective courses* aus dem 2. und 3. Semester zusammengezogen werden) mit ihrem jeweiligen Umfang in ECTS-Punkten und ihren Noten,
b. das Thema der Diplomarbeit,
c. die Note des Prüfungsfaches Diplomarbeit und
d. eine auf den unter a. und c. angeführten Noten basierende Gesamtbeurteilung,
e. den gewählten Schwerpunkt.

Die Note eines Prüfungsfaches ergibt sich durch Mittelung der Noten jener Lehrveranstaltungen, die dem Prüfungsfach über die darin enthaltenen Module zuzuordnen sind, wobei die Noten mit dem ECTS-Umfang der Lehrveranstaltungen gewichtet werden. Die Gesamtnote ergibt sich analog zu den Prüfungsfachnoten durch gewichtete Mittelung der Noten aller dem Studium zuzuordnenden Lehrveranstaltungen sowie der Noten der Diplomarbeit und der kommissionellen Abschlussprüfung.

Lehrveranstaltungen des Typs VO (Vorlesung) werden aufgrund einer abschließenden mündlichen und/oder schriftlichen Prüfung beurteilt. Alle anderen Lehrveranstaltungen besitzen immanenten Prüfungscharakter, d.h., die Beurteilung erfolgt laufend durch eine begleitende Erfolgskontrolle sowie optional durch eine zusätzliche abschließende Teilprüfung.

Der positive Erfolg von Prüfungen ist mit „sehr gut“ (1), „gut“ (2), „befriedigend“ (3) oder „genügend“ (4), der negative Erfolg ist mit „nicht genügend“ (5) zu beurteilen. Lehrveranstaltungen, die in den Modulen „Elective courses“ oder „Freie Wahlfächer“ absolviert werden, können auch mit „mit Erfolg teilgenommen“ bzw. „ohne Erfolg teilgenommen“ beurteilt werden. Diese Lehrveranstaltungen fließen nicht in die oben genannten Mittelungen für die Benotung des Prüfungsfaches und für die Gesamtnote des Studiums ein.

# 9. Studierbarkeit und Mobilität

Die notwendige Bereitschaft zur Mobilität der Studierenden ist ein wesentliches Element des Masterstudium „Mathematical Modelling in Engineering: Theory, Numerics, Applications“. Das erste Semester absolvieren die Studierenden an der Università degli Studi dell'Aquila (im Wintersemester), das zweite Semester an der Technischen Universität Wien (im Sommersemester) und das dritte Semester (im Wintersemester) wahlweise an der Technischen Universität Wien, der Università degli Studi dell'Aquila (L'Aquila) oder der Universitat Autònoma de Barcelona. Das vierte Semester (im Sommersemester) ist für die Anfertigung der Masterarbeit vorgesehen und kann an einer der drei Universitäten absolviert werden. In diesem fest definierten Studienablauf ist es die Pflicht jeder/jedes Studierenden, an allen zwei (bzw. drei) Universitäten in der vorgeschriebenen Reihenfolge zu studieren. Jede Universität steuert somit einen bestimmten Teil zum Studium bei.

Studierende im Masterstudium „Mathematical Modelling in Engineering: Theory, Numerics, Applications“ sollen ihr Studium mit angemessenem Aufwand in der dafür vorgesehenen Zeit abschließen können.

Die Anerkennung von im Ausland absolvierten Studienleistungen erfolgt durch das studienrechtliche Organ.

Um die Mobilität zu erleichtern stehen die in §27 Abs. 1 bis 3 der Studienrechtlichen Bestimmungen der Satzung der Technische Universität Wien angeführten Möglichkeiten zur Verfügung. Diese Bestimmungen können in Einzelfällen auch zur Verbesserung der Studierbarkeit eingesetzt werden.

Lehrveranstaltungen, für die ressourcenbedingte Teilnahmebeschränkungen gelten, sind in der Beschreibung des jeweiligen Moduls entsprechend gekennzeichnet, sowie die Anzahl der verfügbaren Plätze und das Verfahren zur Vergabe dieser Plätze festgelegt.

Die Lehrveranstaltungsleiterinnen und Lehrveranstaltungsleiter sind berechtigt, für ihre Lehrveranstaltungen Ausnahmen von der Teilnahmebeschränkung zuzulassen.

# 10. Diplomarbeit

Die Diplomarbeit ist eine wissenschaftliche Arbeit, die dem Nachweis der Befähigung dient, ein wissenschaftliches Thema selbstständig inhaltlich und methodisch vertretbar zu bearbeiten. Das Prüfungsfach Diplomarbeit, bestehend aus der wissenschaftlichen Arbeit und der kommissionellen Gesamtprüfung, wird mit 30 ECTS-Punkten bewertet, wobei der kommissionellen Gesamtprüfung 3 ECTS zugemessen werden.

Das Thema der Diplomarbeit ist von der oder dem Studierenden in Absprache mit einem Betreuer frei wählbar und muss im Einklang mit dem Qualifikationsprofil stehen.

Die kommissionelle Abschlussprüfung deckt mindestens zwei mathematische oder fachverwandte Gebiete (z.B. aus der Informatik oder dem Maschinenbau) ab.

# 11. Qualitätsmanagement

Das integrierte Qualitätsmanagement gewährleistet, dass das Curriculum des Masterstudiums „Mathematical Modelling in Engineering: Theory, Numerics, Applications“ konsistent konzipiert ist, effizient abgewickelt und regelmäßig überprüft bzw. kontrolliert wird. Geeignete Maßnahmen stellen die Relevanz und Aktualität des Curriculums sowie der einzelnen Lehrveranstaltungen im Zeitablauf sicher; für deren Festlegung und Überwachung sind das studienrechtliche Organ und die Studienkommission zuständig.

Die semesterweise Lehrveranstaltungsbewertung liefert, ebenso wie individuelle Rückmeldungen zum Studienbetrieb an das studienrechtliche Organ, für zumindest die Pflichtlehrveranstaltungen ein Gesamtbild für alle Beteiligten über die Abwicklung des Curriculums. Insbesondere können somit kritische Lehrveranstaltungen identifiziert und in Abstimmung zwischen studienrechtlichem Organ, Studienkommission und Lehrveranstaltungsleiterin und -leiter geeignete Anpassungsmaßnahmen abgeleitet und umgesetzt werden.

Die Studienkommission unterzieht das Curriculum in periodischen Abständen einem Monitoring, unter Einbeziehung wissenschaftlicher Aspekte, Berücksichtigung externer Faktoren und überprüfung der Arbeitsaufwände, um Verbesserungspotentiale des Curriculums zu identifizieren und die Aktualität zu gewährleisten.

## 12. Inkrafttreten

Dieser Studienplan tritt am 1. Oktober 2019 in Kraft.

# A. Lehrveranstaltungstypen und Prüfungsmodalitäten

## Lehrveranstaltungstypen

VO: Vorlesungen sind Lehrveranstaltungen, in denen die Inhalte und Methoden eines Faches unter besonderer Berücksichtigung seiner spezifischen Fragestellungen, Begriffsbildungen und Lösungsansätze vorgetragen werden. Bei Vorlesungen herrscht keine Anwesenheitspflicht.

UE: Übungen sind Lehrveranstaltungen, in denen die Studierenden das Verständnis des Stoffes der zugehörigen Vorlesung durch Anwendung auf konkrete Aufgaben und durch Diskussion vertiefen. Entsprechende Aufgaben sind durch die Studierenden einzeln oder in Gruppenarbeit unter fachlicher Anleitung und Betreuung durch die Lehrenden (Universitätslehrerinnen und -lehrer sowie Tutorinnen und Tutoren) zu lösen. übungen können auch mit Computerunterstützung durchgeführt werden.

VU: Vorlesungen mit integrierter übung vereinen die Charakteristika der Lehrveranstaltungstypen VO und UE in einer einzigen Lehrveranstaltung.

LU: Laborübungen sind Lehrveranstaltungen, in denen Studierende in Gruppen unter Anleitung von Betreuerinnen und Betreuern experimentelle Aufgaben lösen, um den Umgang mit Geräten und Materialien sowie die experimentelle Methodik des Faches zu lernen. Die experimentellen Einrichtungen und Arbeitsplätze werden zur Verfügung gestellt.

PR: Projekte sind Lehrveranstaltungen, in denen das Verständnis von Teilgebieten eines Faches durch die Lösung von konkreten experimentellen, numerischen, theoretischen oder künstlerischen Aufgaben vertieft und ergänzt wird. Projekte orientieren sich an den praktisch-beruflichen oder wissenschaftlichen Zielen des Studiums und ergänzen die Berufsvorbildung bzw. wissenschaftliche Ausbildung.

SE: Seminare sind Lehrveranstaltungen, bei denen sich Studierende mit einem gestellten Thema oder Projekt auseinander setzen und dieses mit wissenschaftlichen Methoden bearbeiten, wobei eine Reflexion über die Problemlösung sowie ein wissenschaftlicher Diskurs gefordert werden.

EX: Exkursionen sind Lehrveranstaltungen, die außerhalb des Studienortes stattfinden. Sie dienen der Vertiefung von Lehrinhalten im jeweiligen lokalen Kontext.

## Sonstige Abkürzungen

SWS: Semesterwochenstunde (45-minütige Lehreinheit wöchentlich über ein Semester; die Abhaltung kann auch geblockt erfolgen)

ECTS: Credit nach dem European Credit Transfer System, Maß für den Arbeitsaufwand eines Normstudierenden; ein ECTS Credit entspricht einem mittleren Arbeitsaufwand von 25 vollen Stunden.

# B. Modulbeschreibungen (Module Descriptions)

## B.1. Module group „Programming and scientific computing“

**Standard amount of work for this module group: 5–23 ECTS**

**Learning Outcomes**

*Professional and methodical competences:* The students know the below mentioned contents and hence master the listed programming languages and strategies, as well as some important algorithms for the numerical treatment of (partial) differential equations.

*Cognitive and practical competences:* The students have a basic knowledge of programming, scientific computing, parallel architectures, and programming models.

*Social skills and self-competences:* Development of individual ideas to solve problems. Presentation at the blackboard. Development of solutions in groups.

**Course topics in this module group**

*Scientific programming in mathematics:* Object oriented design and programming (e.g. in C++). Topics to be covered: variables and standard data types, pointers, functions and recursion, call by value vs. call by reference, loops, objects and classes (resp. structures), operator overloading, inheritance and virtual, templates

*Programming with MATLAB:* MATLAB syntax (command- and object-oriented), graphical representations, problems in linear algebra, optimization and statistics, solution of differential equations by functions in various toolboxes.

*Introduction to Python programming for geoscience:* Python overview, Packages explained, Python Development Environment, Python basics (Variables, Control Structures, Functions, ...), Important packages (Numpy, Scipy, Pandas, Matplotlib), File I/O, Error Handling, Advanced concepts (Iterators, Generators, Object oriented programming), Profiling and optimisation, Testing, Documentation.

*Numerical simulation and scientific computing I:* This course covers basics in computer architectures, performance optimisation, scientific programming with C/C++/Python, partial differential equations, finite difference method, solvers, research software engineering, shared- and distributed-memory parallelization with OpenMP and MPI on multi-core and cluster systems, ray tracing and surface tracking methods.

*High performance computing:* Basic understanding of motivation and goals of parallel computing, basic knowledge of parallel architectures, programming models, languages and interfaces (concrete examples OpenMP, Cilk, MPI), performance analysis and modelling, pitfalls, basic programming skills in the discussed parallel interfaces.

**Expected Prerequisites**

*Professional and methodical competences:* Material of the courses that is common to all mathematics bachelor studies at Technische Universität Wien (in particular solid knowledge of Analysis 1–3, Numerical mathematics, basic programming skills, and some knowledge of ordinary differential equations); moreover some knowledge of partial differential equations.

*Cognitive and practical competences:* The contents and methodology of the above listed courses should be familiar and mastered; moreover usage of PCs, internet, standard software (at least word processing, handling of typical user interfaces), simple programming abilities.

*Social skills and self-competences:* Ability to master the organizational challenges of the theoretical and exercise courses, capability of independent communication with colleagues.

**Compulsory requirements for this module group, as well as the individual courses**

None.

**Applicable teaching and learning forms including assessment of performance**

Lecture on the theoretical foundations and essential tools of the before mentioned chapters as well as illustration of their application in (programming) examples. Oral and/or written exams with computational/programming examples and theoretical questions.

Practising of the learned material via the independent solving of practical examples (including programming exercises). Assessment of performance via regular homework, performance at the blackboard and/or programming projects and/or tests.

**Courses in this module group**

| | SWS | ECTS |
|---|---|---|
| Module *Computer programming* (compulsory) | | |
| Scientific programming in mathematics VU | 2 | 3 |
| Programming with MATLAB VU | 2 | 2 |
| | | |
| Module *Scientific computing* (compulsory in topical focus MN) | | |
| Introduction to Python programming for geoscience VU | 1 | 1.5 |
| AKNUM Numerical simulation and scientific computing I VO | 3 | 4.5 |
| AKNUM Numerical simulation and scientific computing I UE | 1 | 1.5 |
| Numerical simulation and scientific computing I VU | 3 | 6.0 |
| High performance computing VU | 3 | 4.5 |
| | | |
| *Elective module A (one of the following items has to be chosen)* | | |
| Introduction to parallel computing VU | 4 | 6 |
| AKNUM, AKOR Numerical optimisation VO+UE | 4 | 6 |
| Basics of Parallel Computing VU + Energy-efficient Distributed Systems VU | 4 | 6 |
| Iterative solution of large systems VO+UE | 4 | 6 |

In the module *Scientific computing* only Numerical simulation and scientific computing I VU or only AKNUM Numerical simulation and scientific computing I VO+UE may be chosen.

**Restrictions due to limited resources**

None.

## B.2. Module group „Numerics“

**Standard amount of work for this module group: 15–34 ECTS**

**Learning Outcomes**

*Professional and methodical competences:* The students know the below mentioned contents and hence master important algorithms for the numerical treatment of ODEs and PDEs as well as modern applications of (nonlinear) PDEs in natural and technical sciences.

*Cognitive and practical competences:* The students have a basic knowledge of the numerical treatment of PDEs including its implementation. They understand the essential properties of the most important numerical method classes as well as some differential equation models.

*Social skills and self-competences:* Development of individual ideas to solve problems. Presentation at the blackboard. Development of solutions in groups.

**Course topics in this module group**

*Numerics of differential equations:* Knowledge of standard discretization methods for the approximation of solutions of ordinary differential equations. Initial and boundary value problems for ordinary differential equations, one-step and multistep method, symplectic integrators, step-size control (adaptivity). Introduction to numerical methods for partial differential equations.

*Numerical methods for PDEs:* Variational formulation of PDEs and function spaces, Finite element convergence theory, Discontinuous Galerkin methods for convection dominated problems, Mixed methods and applications in fluid mechanics, Nonlinear equations and applications in solid mechanics, Vectorial function spaces and applications in electromagnetics, Instationary PDEs and time-stepping methods, Analysis of iterative solvers and preconditioners, A-posteriori error estimates and adaptivity

*Numerical methods in fluid dynamics:* Introduction to advanced methods of computational fluid dynamics. Methods for a treatment of convection-diffusion equations, projection methods for incompressible and compressible Navier-Stokes equations, treatment of complex geometries, turbulence modelling.

*Finite element methods for multi-physics:* Finite-Element method and aspects for computer implementation, computation of mechanical problems, coupled field problems (theory of magnetic, mechanical and acoustic fields; design process of modern sensors and actuators), optimisation of modern mechatronic systems (numerical simulation of electromagnetic actuators, of piezoelectric positioning drives, vibrational induced sound generated by machines and automobiles, etc.).

*Calculating turbulent flows with CFD-codes:* Creation of the geometry, grid generation, adjustment and selection of fluid dynamical models and parameters, turbulence models and boundary treatment, representation and interpretation of the results.

*Numerical optimisation:* Unconstrained optimisation: gradient methods, classical Newton method, quasi-Newton method (e.g. BFGS method); Constrained optimisation: trust region methods, linear programming (simplex method, interior point method), quadratic programming (inner point method, active sets method), sequential quadratic programming

### Expected Prerequisites

*Professional and methodical competences:* It is expected that students are familiar with the contents of the courses Analysis 1-3, Linear algebra 1,2, numerical mathematics and programming; moreover sound knowledge of ordinary and partial differential equations and Functional analysis 1. The courses on Fluid dynamics and Multi-Physics require a basic knowledge of physical principles and, in particular, mechanics.

*Cognitive and practical competences:* The contents and methodology of the above listed courses should be familiar and mastered; moreover simple programming abilities.

*Social skills and self-competences:* Ability to master the organizational challenges of the theoretical and exercise courses, capability of independent communication with colleagues.

### Compulsory requirements for this module group, as well as the individual courses

None.

### Applicable teaching and learning forms including assessment of performance

Lecture on the theoretical foundations and essential tools of the before mentioned chapters as well as illustration of their application in examples. Oral and/or written exams with computational examples and theoretical questions.

Practising of the learned material via the independent solving of practical examples (including programming exercises). Assessment of performance via regular homework, performance at the blackboard and/or programming projects and/or tests.

**Courses in this module group**

| | SWS | ECTS |
|---|---|---|
| Module *Numerics for differential equations* (compulsory) | | |
| Numerics of differential equations VO | 4 | 5 |
| Numerics of differential equations UE | 4 | 3 |
| AKNUM Numerical methods for PDEs VO | 3 | 4 |
| AKNUM Numerical methods for PDEs UE | 2 | 3 |
| | | |
| *Elective module B* | | |
| Numerical methods in fluid dynamics VO | 2 | 3 |
| Numerical methods in fluid dynamics UE | 2 | 2 |
| Finite element methods for multi-physics VO | 2 | 3 |
| Finite element methods for multi-physics UE | 2 | 2 |
| Finite element methods for multi-physics I VU | 3 | 4 |
| Calculating turbulent flows with CFD-codes UE | 2 | 3 |
| AKNUM, AKOR Numerical optimisation VO | 3 | 4.5 |
| AKNUM, AKOR Numerical optimisation UE | 1 | 1.5 |

In the module *Elective module B* only Finite element methods for multi-physics I VU or only Finite element methods for multi-physics VO and/or Finite element methods for multi-physics UE may be chosen.

**Restrictions due to limited resources**

None.

## B.3. Module group „Analysis“

**Standard amount of work for this module group: 6–25 ECTS**

**Learning Outcomes**

*Professional and methodical competences:* Knowledge of the below mentioned contents as well as methods of proof and computation, which appear in the modules listed subsequently.

*Cognitive and practical competences:* Further development and deepening of the skills acquired in the previous modules, such that the student could – potentially – write a diploma theses in this field.

*Social skills and self-competences:* Development of individual ideas to solve problems. Presentation at the blackboard. Development of solutions in groups.

**Course topics in this module group**

*Modelling with partial differential equations:* Treatment of several selected application problems from natural sciences (e.g. from fluid dynamics) and technical sciences by means of (mostly nonlinear) partial differential equations. This includes modelling aspects, the analysis and numerics of the involved PDEs, as well as the interpretation of the solution for an application problem.

*Functional analysis 2:* Gelfand transformation, spectral theorem for bounded normal and, in particular, unitary operators on Hilbert spaces, spectral theorem for unbounded selfadjoint operators on Hilbert spaces, strongly continuous semigroups, theorem of Hille-Yoshida.

*Stationary processes and time series analysis:* Multivariate (weakly) stationary processes in discrete time, autocovariance function, spectral representation, spectrum, linear filters, transfer function, AR/ARMA processes, forecasting, Wold representation, estimation.

*Stochastic analysis in financial and actuarial mathematics 1:* Repetition of the basic definitions of probability theory, continuity theorem of Lévy; Definition and properties of multidimensional normal distributions, Gauß processes, Brownian motion/Wiener process, existence theorem of Brownian motion; Definition of Itô-integrals, Itô-isometry, martingales and martingal inequalities, elementary properties of the Itô-integral, one- and multidimensional Itô-formula, martingal representation, Bayes-formula; Lévy characterization of the Brownian motion, theorem of Girsanov, exponential martingales, Kazamaki-condition, Novikov-condition.

### Expected Prerequisites

*Professional and methodical competences:* It is expected that students are familiar with the contents of the courses Analysis 1–3, Linear algebra 1,2, (linear) Partial differential equations as well as Measure theory. The course Functional analysis 2 requires knowledge of Functional analysis 1. The courses Stationary processes and time series analysis as well as Stochastic analysis require foundations of measure and probability theory, and basics of statistics and stochastic processes.

*Cognitive and practical competences:* The contents and methodology of the listed courses should be familiar and mastered to such a degree, that the student can make theoretical considerations and can solve concrete problems independently.

*Social skills and self-competences:* Ability to master the organizational challenges of the theoretical and exercise courses, capability of independent communication with colleagues. In particular for the course Modeling with PDEs: contact with the application and practitioner's perspective of mathematical problems.

### Compulsory requirements for this module group, as well as the individual courses

None.

### Applicable teaching and learning forms including assessment of performance

Lecture on the theoretical foundations and essential tools of the before mentioned chapters as well as illustration of their application in examples. Oral and/or written exams with computational examples and theoretical questions.

Practising of the learned material via the independent solving of practical examples. Assessment of performance via regular homework, performance at the blackboard and/or tests.

**Courses in this module group**

| | SWS | ECTS |
|---|---|---|
| Module *Modelling* (compulsory in topical focus MN) | | |
| Modelling with PDEs VO | 3 | 4.5 |
| Modelling with PDEs UE | 1 | 1.5 |
| | | |
| *Elective module C* | | |
| Functional analysis 2, VO | 3 | 4.5 |
| Functional analysis 2, UE | 1 | 1.5 |
| Stationary processes and time series analysis VO | 3 | 4.5 |
| Stationary processes and time series analysis UE | 1 | 1.5 |
| Stochastic analysis in financial and actuarial mathematics 1 VO | 3 | 5 |
| Stochastic analysis in financial and actuarial mathematics 1 UE | 1 | 2 |

**Restrictions due to limited resources**

None.

## B.4. Module „German“

**Standard amount of work for this module group: 4–6 ECTS**

**Learning Outcomes**

Students will reach a basic level of both written and spoken German (A1 level according to CEFR).

#### Course topics in this module group

*German (A1 level):* Greetings and introductions. Expressing likes and dislikes. Talking about daily activities. Understanding and using everyday expressions as well as basic phrases related to daily needs (buying something, asking for directions, ordering a meal). Interacting in a very simple way about known topics (family, nationality, home, studies).

#### Expected Prerequisites

No previous knowledge in German is expected.

#### Compulsory requirements for this module

None.

#### Applicable teaching and learning forms including assessment of performance

Communicative teaching approach; oral and written assessment of the language competence.

#### Courses in this module group

German courses at the level A1 with the option to earn ECTS credits are offered by:

- Sprachenzentrum der Universität Wien (4 ECTS)
- TU & Innes Institute Vienna (4–6 ECTS depending on length)

Both of these courses are offered by external institutions and hence they are with costs.

#### Restrictions due to limited resources

None.