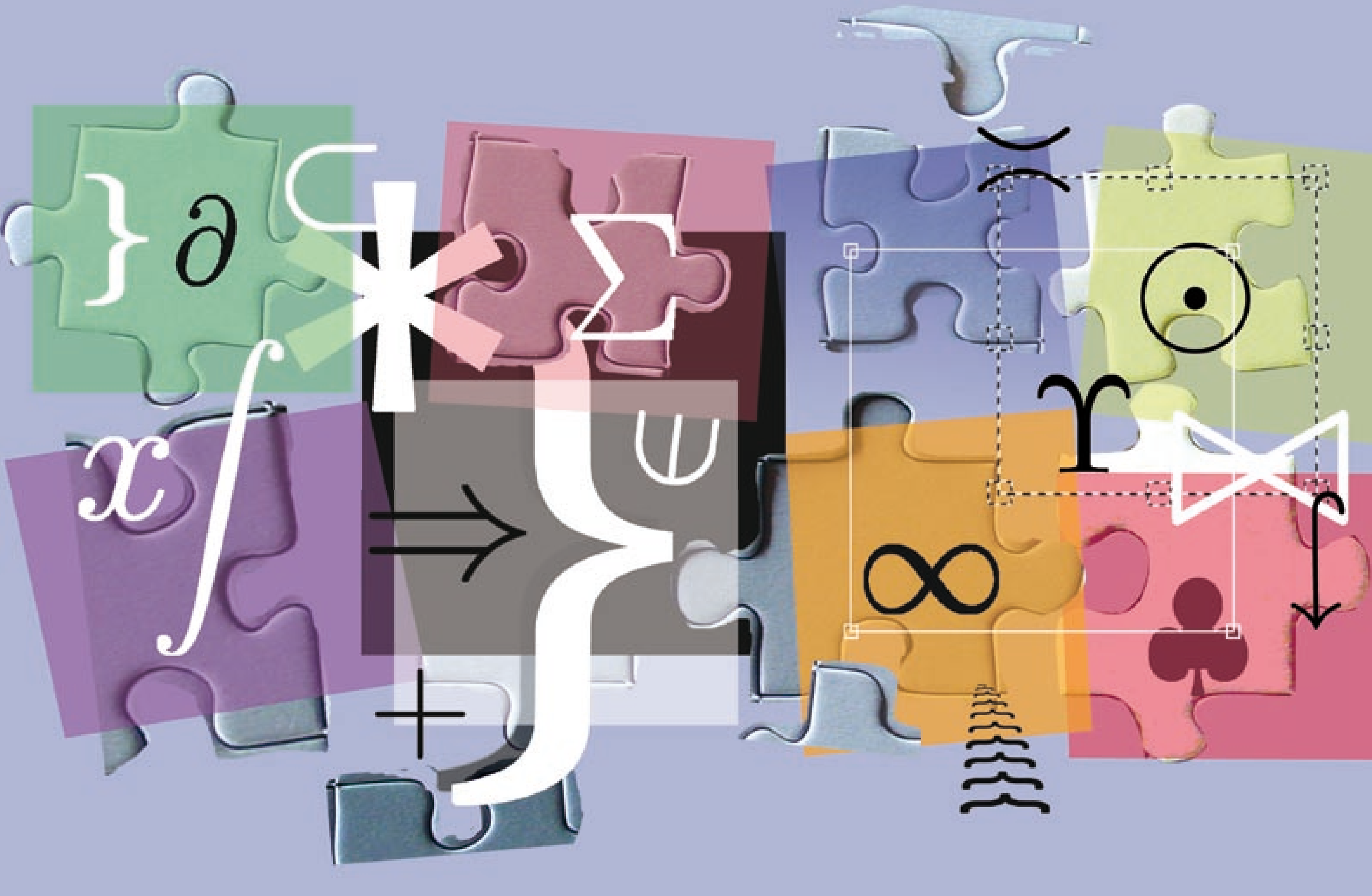
MASTER

Master of Science in Mathematics
Master of Science in Applied Mathematics



Departement Mathematik
Department of Mathematics

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

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ETH Zurich, Main Building, Poly Terrace

Welcome to the ETH Zurich

About the ETH Zurich

The ETH Zurich – the Swiss Federal Institute of Technology Zurich – was founded in 1855 and has long been recognized as a global leader in research and education. Excellent conditions for learning and research, state-of-the-art facilities on two campuses and an attractive urban environment provide an ideal setting for some of the brightest minds internationally. ETH Zurich is academic home to 18,000 students, researchers, faculty and staff members of about 90 nationalities.
The ETH Zurich offers 22 different three-year Bachelor's programmes. Each of these is followed by a consecutive Master's programme of one-and-a-half or two years' duration. Additional, specialized Master's programmes offer the opportunity to focus on interdisciplinary or emerging subject fields. Master's programme graduates wishing to pursue a career in research can continue in doctoral programmes.

About the Departement of Mathematics

The ETH Zurich comprises 16 departments. The facilities of D-MATH – the Department of Mathematics – are located right in the heart of Zurich in the historic ETH main building. In this department over 40 faculty and senior scientists, and 110 assistants and doctoral students represent a wide range of research areas and support about 300 Bachelor's and 100 Master's students. About one-third of scientific staff is grouped in three institutes: the Institute for Operations Research (IFOR), the Seminar for Applied Mathematics (SAM) and the Seminar für Statistik (SfS).

About the Master's programme

The D-MATH offers two consecutive Master's programmes: the **Master's programme in Mathematics,** leading to either a degree in Mathematics or Applied Mathematics; and the **Master's programme in Computational Science and Engineering (CSE).** In addition, it offers a spezialized **Master's programme in Statistics** and programmes leading to a **Master of Advanced Studies in Secondary and Higher Education** and a **Master of Advanced Studies in Finance.**

This brochure presents the consecutive Master's programme in Mathematics.

Master‘s programme in Mathematics

The Master’s programme in Mathematics serves to broaden the basic knowledge acquired during the ETH Zurich Bachelor’s programme in Mathematics or the equivalent. Here students may focus on a particular direction in various mathematical fields and gain either a Master’s degree in Mathematics or a Master’s degree in Applied Mathematics (the choice of title may be made as programme completion approaches). With the knowledge they obtain, graduates of this programme are able to use and adapt mathematical methods, recognise and analyse mathematical structures, and confidently approach other areas of knowledge via literature. Optional general education courses in the Humanities and Social and Political Sciences provide a useful complement to the programme. The Master’s degree title both prepares graduates to take up employment and qualifies them to pursue doctoral studies.

The Master’s programme in Mathematics is designed to be completed within one-and-a-half years, which include a period of five months during which the Master’s thesis is written. The maximum duration of study is three years. In accordance with European Credit Transfer System (ECTS) regulations the programme is credit-based: a total of 90 credits must be earned to qualify for the Master’s degree.

Master‘s degree in Mathematics

To obtain the Master’s degree in Mathematics students may choose from a broad range of core courses, electives and seminars (see page 7 for a full description). Minimum requirements include

- 36 credits from core courses and electives, of which 16 are from core courses
- 12 credits from seminars and semester papers, including at least one seminar

The programme concludes with a Master’s thesis (30 credits).

Graduates hold the academic title **Master of Science ETH in Mathematics.**

Master‘s degree in Applied Mathematics

The requirements for the Master’s degree in Applied Mathematics are similar, but students are required to focus to a certain extent on an area of Applied Mathematics such as Insurance Mathematics and Financial Engineering; Operations Research; Numerical Analysis and Scientific Computing; or Statistics. In addition, students must select an application area (see page 7). Minimum requirements include

- 28 credits from core courses and electives, of which 16 are from core courses and
  15 from the applied focus area
- 8 credits from the selected application area
- 14 credits from seminars and semester papers, including one semester paper relevant to the chosen application area

The programme concludes with a Master’s thesis (30 credits).

Graduates hold the academic title **Master of Science ETH in Applied Mathematics.**

Courses, seminars and the Master‘s thesis

Core courses

Core courses serve as a foundation in specific areas of Pure or Applied Mathematics and in application-oriented areas such as Physics or Computer Science. A core course typically comprises four hours of lectures plus one hour of tutorials per week. Core courses, selected by the individual student, are divided into two subcategories: essentially, courses in Pure Mathematics, and courses in Applied Mathematics and other application-oriented areas.
Core courses offered in recent years include Differential Geometry, Functional Analysis, Algebraic Topology, Probability Theory, Statistics, Numerics of PDEs, General Mechanics, Theoretical Physics, Theoretical Computer Science, and others.

Electives

Electives usually comprise two or three lecture hours per week and serve to broaden students’ knowledge of specific subject areas. Electives, also selected by the individual student, are divided into the same subcategories as core courses. Students may also attend other core courses instead of taking electives.

Application area

Courses in this category are only required for the Master’s degree in Applied Mathematics, and include courses run by other ETH Zurich departments. These courses serve to impart knowledge in technology and science in areas where Mathematics plays an essential role. Currently students may select among the following: Atmospherical Physics, Computational Biology, Electromagnetics, Control and Automation, Economics, Environmental Science, Finance and Insurance, Image Processing and Computer Vision, Information and Communication Technology, Material Modelling and Simulation, Operations Management, Quantum Chemistry, Simulation of Semiconductor Devices, Systems Design, Theoretical Physics, and Transportation Science.

Seminars and semester papers

During seminars each student works independently on certain material and makes a presentation to other seminar participants. Seminars, selected by the individual student, broaden basic knowledge and extend specialization in specific subject areas in addition to the presentation practice they provide.
Semester papers on a selection of topics help to deepen students’ knowledge of a specific subject area, sharpen their capacity for independent mathematical work, and enhance their ability to present mathematical results in writing.

Compulsory electives in the Humanities, Social and Political Sciences

Students may choose from a range of general education courses in the Humanities, Social and Political Sciences (D-GESS), such as International Environmental Politics, Patent Law and License Contracts, Social Network Analysis, and others.

Master‘s thesis

The Master’s thesis concludes the programme, and involves the independent authorship of a major piece of work on a mathematical topic following the consultation of literature, problem-solving, and the written compilation of results.

Research areas in Mathematics*

Algebra and Number Theory

Arithmetic Algebraic Geometry:

Elliptic curves, Abelian varieties, Drinfeld modules, Function fields, Shimura varieties, Motives, Galois representations, Monodromy groups, Group schemes.

Diophantine Approximation:

Transcendental number theory, Linear forms, Linear forms in logarithms, Transcendence, Elliptic and abelian functions.

Automorphic Forms:

Modular forms, Hilbert and Siegel modular groups and automorphic forms, Jacobi forms, Dirichlet series of one or several variables, Zeta and L-functions, Periods, Modular symbols, Spectral theory, Selberg trace formula, Eisenstein series, Selberg zeta function.

Analytic Number Theory:

Multiplicative problems, Sieve methods, Applications of automorphic functions.

Geometry

Differential Geometry:

Spaces of nonpositive curvature, Gromov hyperbolic spaces and groups, Asymptotic geometry, Geometry and analyis on metric spaces, Kaehler and hyperkaehler geometry.

Lie groups and Discrete Subgroups:

Group actions on trees and products of trees, Kleinian groups, Bounded cohomology of locally compact groups, Applications in rigidity theory, Group actions on symmetric spaces, Ergodic theory on Lie groups.

Representation Theory:

Representation theory of algebraic groups and Lie algebras, Cluster algebras, Cluster categories and their geometric models, Geometry of secant varieties, Representation theory of algebras and quivers.

Geometric Topology:

Invariants of knots and links in three-manifolds, Knots in complex algebraic geometry (quasipositive knots) and contact geometry (Legendrian ribbons).

Symplectic Geometry:

Gromov-Witten invariants, Floer homology, Hamiltonian dynamics, Lagrangian submanifolds, Pseudoholomorphic curves, ASD instantons, Moment maps, Symplectic vortex equations, Complex symplectic structures, Contact geometry, Symplectic field theory, Fukaya categories, Mirror symmetry, Seiberg-Witten and Donaldson invariants.

* The following research areas in Pure Mathematics are presently represented at the D-MATH. See also **http://www.math.ethz.ch/research/areas.**

Analysis

Variational Methods:

Applications of minimax methods and Morse theory in geometric variational problems such as prescribed scalar curvature equations, Analysis of concentration-compactness phenomena and energy quantization effects.

Geometric Flows:

Ricci flow, Flow by mean curvature, Scalar curvature flows such as Yamabe flow, Calabi flow or Q-curvature flow, Wave maps.

Partial Differential Equations:

Wave maps, Hyperbolic conservation laws, Shocks and defects, Viscosity solutions to fully nonlinear degenerate elliptic and parabolic equations, Deterministic and stochastic control, Reaction diffusion equations, Wave front propagation, Ergodic and homogenization problems.

Dynamical Systems:

Chaotic behaviour of dynamical systems, Shadowing techniques, Periodic solutions, Applications to celestial mechanics, Restricted three-body problem.

Mathematics and Physics

General Relativity and Fluid Mechanics:

Stability of solutions of Einstein‘s equations, Gravitational waves, Formation of singularities.

Condensed Matter Theory:

Quantum many-body systems of bosons and fermions.

Quantum Field Theory and Statistical Mechanics:

Quantum integrable systems, Deformation quantization, Index theory, Random matrices, Special functions.

Probability Theory

There are numerous links of Probability Theory with both Pure and Applied Mathematics. Among topics of relevance for the Master’s programme are for instance: Stochastic processes, Markov processes, Gaussian processes, Brownian motion, Stochastic analysis, Stochastic differential equations, Stochastic partial differential equations, Dirichlet forms, Large deviations, Particle systems, Coalescents, Concentration of measure, Random media, Percolation, Random walks and diffusions in random environment, Ageing, Spin glasses, Random walks on graphs.

Focus areas in Applied Mathematics

Mathematics of Finance and Insurance

Over the last few decades we have developed an internationally highly visible programme in Insurance Mathematics and Financial Engineering. This programme comprises a mathematically-oriented course which covers a broad selection of topics and can lead to the actuary qualification (as defined by the Swiss Association of Actuaries). It also gives interested students a training platform in the broad area of Quantitative Risk Management and Financial Engineering.

The field of Mathematical Finance covers a very broad spectrum of topics ranging from the very theoretical to the very applied. It intersects, in particular, with the areas of probability theory (stochastic processes), insurance mathematics (financial engineering), numerical analysis (computational finance) and operations research (energy markets), among others. It interfaces in both research and teaching with the activities of the University of Zurich Swiss Banking Institute (ISB).

Insurance Mathematics and Financial Engineering:

Risk theory, Non-life and life insurance mathematics, Quantitative risk management, Market-consistent actuarial valuation, Asset and liability management, Financial modeling and indifference pricing, Credibility theory, Stochastic claims reserving methods, Economic theory of financial markets.

Mathematical Finance:

Risk measures, Incomplete markets, Backward stochastic differential equations and their applications, Dynamic hedging and valuation approaches.

Numerical Analysis and Scientific Computing

In this focus area students concentrate on the mathematical analysis and computer implementation of advanced numerical solution methods for mathematical models in science and engineering. Their work is motivated by several developments in Applied Mathematics, in particular the growing omnipresence of mathematical modelling in the sciences, encompassing fields such as biology, finance, socioeconomic systems, psychology, and others.
Numerical analysis plays a key role in developing algorithms for the efficient computer solution of these models and thus greatly influences model development itself. The necessary mathematical tools are borrowed from analysis (partial differential equations, function spaces), approximation theory and linear algebra. Since mathematical algorithm development must take into account advances in both mathematical analysis and hardware development, techniques from computer science also play an important role.
Within D-MATH, core instruction in numerical analysis and scientific computing at all levels is provided by faculty of the Seminar for Applied Mathematics (SAM).

Main Research Areas:

Mathematical and numerical methods for multiscale problems, Efficient discretization and solution of highdimensional boundary value problems, Modelling and numerical simulation of fluids and plasmas, Efficient, stable, and structure-preserving algorithms in numerical linear algebra, Computational electromagnetics, Quantitative finance and insurance, Deterministic and randomized algorithms for stochastic problems, Impact of new hardware paradigms on mathematical algorithm design.

Operations Research

Operations Research deals with the conceptual design, development and implementation of methods and models which support decisions in the areas of design, planning, coordination and control of processes in complex socio-technical systems. The field is the focus of the Institute for Operations Research (IFOR). IFOR's research and teaching cover many areas of Operations Research, and emphasize (mathematical) modelling and formal algorithmic thinking.
Operations Research is also an interdisciplinary subject, and IFOR collaborates in diverse projects with the departments of economics (MTEC), computer science (INFK), transportation science (BAUG), automatic control (ITET), and with industrial partners.

Mathematics of Operations Research:

The technical, mathematical Operations Research group focuses on design of efficient algorithms and the study of structural properties in the area of mathematical optimization, in particular, convex optimization and (parametric) linear complementarity.

Operational Engineering:

The Operational Engineering group is concerned with solving real-world problems by making innovative use and enhancements of mathematical modeling techniques. In particular the following topics have been investigated within industrial research collaborations

- Risk Management in Energy and Emission Markets:
  Dispatch management of hydro power plants, Capacity management and contractual engineering, Value of flexibility of production technologies, Valuation of swing contracts, Equilibria price formation for CO_2 allowance-contracts, Reliability and vulnerability of power-grid operation.

- Transportation and Production Networks:
  Construction of robust railway timetables, Online rescheduling in railway systems, Traffic assignment and equilibrium models for individual transportation systems.

Statistics

The field of statistics is the focus of the Seminar für Statistik institute. All areas of statistics are covered here in research and teaching, with an emphasis on mathematical and computational statistics. Complex statistical modelling is also under development in interdisciplinary collaborations with the environmental, life and natural sciences.

Mathematical Statistics:

Bayesian statistics, Graphical modeling, High-dimensional asymptotics, Learning theory, Machine learning, Nonlinear Kalman filtering, Nonparametric statistics, Spatio-temporal processes, Survival analysis with censored data.

Computational Statistics:

Algorithms for sparse convex optimization problems, Computation of maximum likelihood estimators for censored data survival models, EM-type algorithms, l_q-regularization, Markov chain Monte Carlo, Particle filtering, Resampling, Statistical software.

Applied Statistics:

Statistical methods, Models and data analysis in environmental, life and natural sciences.

Career Opportunities

Corinne Dahinden

PhD student at the Seminar für Statistik, ETH Zurich
Computational modeling of molecular pathways in human renal cell carcinoma

«My job is to develop better mathematical procedures to address the statistical problems of biologists.»

During my mathematics studies at the ETH I focused mainly on Applied Mathematics with a specialization in Statistics and Operations Research. After my studies I decided to do a Ph.D. and entered a Ph.D. programme in Statistics.
My Ph.D. thesis is made up of various projects, all in collaboration with biologists. Currently I am working with renal cell carcinoma data. There are methods to assess how active a certain gene is, and we in fact have information on this activity from a number of genes from patients with renal cell carcinoma. We hope to gain further insight into the underlying biological processes, both to help pathologists refine medication, and to enable early diagnoses of the cancer's development so as to target it more specifically.

Brigitte Häfliger

Actuary at Swiss Life, Zurich
Product development in individual life insurance

«My mathematics studies at the ETH Zurich stood me in good stead for the practical day-to-day work of an actuary.»

I decided early on to specialise in financial and actuarial mathematics. As a student I was able to gain initial hands-on experience through various job placements at a well-known insurance company, giving me an insight into my future career.
Working on my thesis I gained practical experience of specific issues. This work involved deriving the present value of future surplus payments from insurance obligations. I found it extremely interesting to see how the theory was implemented in practice. We based our calculations on theoretical interest rate models from which we determined a reference interest rate. We then used a Monte Carlo simulation approach for our valuations. Such issues have become increasingly relevant in recent years because of the market-consistent valuations used for risk-based solvency calculations.
I now work for Swiss Life in a team of actuaries, assisting in product development for individual life insurance. I am responsible for developing product innovations in line with technical and market requirements, and help solve actuarial issues involved in our existing insurance portfolio.

Anja Handschin-Aschwanden

Teacher, Kantonsschule Luzern
Mathematics

«I was glad to be able to combine my studies in mathematics with courses in didactics.»

During my mathematics studies at the ETH I already knew that I would like to become a teacher, and therefore I started attending courses and seminars in didactics in my third year there. At the same time I was able to gain initial experience as a teacher as a substitute in several schools at various levels. I wrote my diploma thesis on dynamical systems, which resulted in a paper with D. Stoffer and A. Schulze-Halberg.
I now work as a maths teacher at the Kantonsschule Luzern, which is the biggest grammar school in Switzerland. Every lesson is highly individual and depends among other things on the participation of the students and the atmosphere in the classroom. For me it is wonderful to work with young people. I like showing them how to convert an everyday problem into a math-

ematical equation or to subdivide a difficult problem into smaller units. I normally teach the same class for several years, and it is fascinating for me to see the teenagers expand their knowledge, hone their skills, develop their attitudes and become more and more independent during this time.

Lukas Finschi

Leading Researcher, Schindler Aufzüge AG, Ebikon
Efficient transportation in buildings

«Mathematics helps us not only to analyse and solve problems, but also opens the view for opportunities which may change the world.»

I decided to study mathematics at the ETH simply because I loved to, without knowing what I would do later. And I loved the course, both the pure theoretical and Applied Mathematics. I got the opportunity early to collaborate in research projects at the Institute for Operations Research (IFOR), and it was not a difficult decision to extend my studies with a Ph.D. at IFOR. Although my thesis focused more on theoretical aspects of Operations Research (i.e., discrete and computational geometry), I continued to do applied work, which included industry partners such as Schindler Aufzüge AG. These partners were looking at opportunities to use available resources (e.g. production machines or elevators) more efficiently or to change systems to make better solutions possible. Today we are seeing the success of this work, and how it has started to change the world, making transportation in buildings much more efficient than it ever was. It is my mission, together with a research team which includes other ETH researchers, to lead the way here. One day you might join us!

Thomas Herrmann

Traffic Consultant at R+R Burger und Partner AG, Baden
Methods and models for decision support, benchmark evaluation, process flow optimization, research analyses and studies

«Mathematics helps me to analyse, model and solve complex traffic problems, as well as to present the results in an understandable way even for non-experts.»

For me, the fascination of mathematics lies in the problem-solving process. Real-world issues have to be transformed into mathematical language, which is then used to analyse them. Without understanding the modelling methods, solution approaches and algorithms applied to the problem, results cannot be interpreted correctly and thus cannot be transformed back into the real-world context. Therefore I attended lectures on topics in Applied Mathematics, mainly in the domain of Operations Research and Theoretical Computer Science. In addition, as Statistics provides important tools for presenting results I also chose some Statistics lectures.
During my Ph.D. I took part in a collaborative project established between the Institute for Operations Research (IFOR) at the ETH and the Swiss Federal Railways (SBB) to analyse the capacity of railway networks and the stability of timetables. Thanks to mathematical and computer science methods, it was possible to gain deeper insights into the processes of capacity optimization of an existing railway network or stability improvements of dense timetables. The complexity of these railway problems necessitated the development of specific solution approaches, which were considerably supported by mathematics. While working on the project I also gained an understanding of specific railway-related issues and learned much about railway technology.
Economic and financial aspects played a minor role during my time at the ETH, but today there is an increased focus on costs and benefits. Today I use mathematics in an interdisciplinary environment with traffic engineers and economists. Mathematical tools and analytical thinking processes are crucial for dealing with the challenges which crop up in my daily work.

Admission

Students holding a Bachelor's degree in Mathematics from the ETH Zurich or the University of Zurich can enrol directly for the Master's programme. Students from other universities must hold a Bachelor's degree that corresponds to at least 180 ECTS credits; hold an equivalent university degree; or provide evidence of equivalent academic achievements. In addition, candidates must be able to prove that they qualify for the Master's programme in Mathematics at their home university, should such a programme be available. Applicants must also demonstrate an adequate knowledge of English. Further restrictions may also apply, for instance if there are limits on the number of students that can be accommodated in a particular group or focus area.
To apply, please follow the instructions found at
http://www.rektorat.ethz.ch/students/admission/master/index_EN.

The responsible Admissions Committee will evaluate applications according to candidates' academic qualifications. The syllabus and the demands of the ETH Zurich Bachelor's programme in Mathematics serve as guidelines.
If the outcome is favourable, final admission may be subject to additional requirements, i. e., additional courses to be taken at the outset of the ETH Zurich course to complement candidates' previous education.
For more detailed information regarding admission please refer to Chapter 3 and the Appendix of the Programme Regulations, available at
http://www.math.ethz.ch/education/master/regulations.

Information

For information concerning admission or copy orders please contact

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For further information concerning the Master's programmes please visit the following websites:

http://www.math.ethz.ch/education/master
http://www.ethz.ch/prospectives/index_EN

View of City Zurich from the ETH Zurich, Poly Terrace

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