CENTRAL EUROPEAN UNIVERSITY

Department of Mathematics and its Applications

Two Year MS Program

Student Handbook

Accredited by NYSED in 2008

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Table of Contents

Introduction

Degree offered:	Master of Science (MS) in Applied Mathematics
Length of study:	2 years
Graduation requirements:	45 course credits + 5 research credits + thesis (worth 10 credits)
Language of instruction:	English

The CEU Mathematics Department offers a **two-year Master of Science (MS) program in Mathematics and its Applications**, accredited in the US, in cooperation with the Alfréd Rényi Institute of Mathematics, Hungarian Academy of Sciences, home of **Abel Prize laureate Endre Szemerédi**. In order to broaden the perspectives for students, the mathematics department collaborates closely with Departments of Network Science, Cognitive Science, Economics and Business School, and with other universities in Budapest in the fields of data science, financial mathematics and cognitive science. Upon graduation, the MS program enables students to become high profile professionals in fields applying for example statistics, financial mathematics or bioinformatics on the one hand, or continue their study for PhD at some prestigious universities around the World in mathematics or science.

As a community of students, faculty and staff, the *Department of Mathematics and its Applications* is committed to academic freedom, equal access to education and collegial self-governance. Our ultimate aim is to enable our diverse student body to become successful and influential professional scientists in the future social and academic life of their home countries and abroad.

Our M.S. program is unique since:

• It is an international graduate program in English in Central Europe.

• It offers the possibility to cooperate with the Network Science Center, and the Departments of Cognitive Science, Economics, Sociology and Social Anthropology and Political Science.

• The program can benefit from the opportunities offered by the rich local academic environment, including the Alfréd Rényi Institute of the Hungarian Academy of Sciences (HAS), the Budapest University of Technology and Economics (BME), the Computer and Automation Research Institute of the HAS, and the Eötvös Lorand University (ELTE).

Admissions

Students seeking admission to our MS program have to meet both the general CEU application requirements and the requirements of the Mathematics Department, as follows.

General CEU Admissions Requirements

are available at https://www.ceu.edu/admissions

Specific Requirements of the Mathematics Department

Applicants are required to submit a one-page *statement of purpose* describing their interest in mathematics, achievements and future goals. In addition, they have to prove familiarity with fundamental undergraduate material, by taking either a Mathematics Exam (for a list of subjects to be covered on the exam see the Annex 2 below) or the GRE Subject Test in Mathematics. In addition, candidates passing the threshold set by the department for the written tests will be interviewed (on the basis of the list of subjects of in Annex 1).

Program learning outcomes

Prospective MS students are expected to possess a good knowledge of the fundamentals in mathematics, especially in algebra and analysis in the areas described in the Annex 2.

The learning outcome of the Mathematics and its Applications M.S. program can be classified into three major clusters: **knowledge**, **skills** and **attitudes/values**.

Knowledge

- Fundamental knowledge in three fundamental areas of mathematics, Algebra, Analysis and Probability,
- State of the Art knowledge in the student's specific area of interest,
- Possessing the fundamental tools and the way of their use in the student's specific area of research,
- Ability to measure the difficulty of a mathematical problem, and to understand mathematical arguments, including discerning the core ideas,

- Understanding the interdisciplinary aspects of scientific research, like connections of the student's specific area of research to other fields in mathematics, science or social sciences,
- Wherever it is possible, learning about applications of mathematical research.

Skills

- Ability to organize the solution of a mathematical problem into suitable smaller tasks,
- Ability to cooperate with fellow researchers,
- Ability to communicate ideas orally,
- Ability to present a mathematical topic orally either to experts, or to a wider mathematical audience,
- Ability to present own ideas in writing in a way such that it is accessible to fellow researchers,
- Ability to work in teams,
- Ability to organize a task, to set out priorities.

Attitudes/values

- Highest international standards in research and teaching,
- Promotion of openness, self-reflection, and critical thinking. Pursuit of truth wherever it may lead, and resolution of differences through debate, not denial.
- Interdisciplinary and problem-focused approaches to teaching and research,
- Preserving a multiple intellectual identity by the diversity of students,
- Educating students to be citizens of the world, connected to their own communities and to others different from themselves.

Program Structure and Graduation Requirements

This is a two-year program in Mathematics and its Applications, including coursework, research and thesis components.

The MS regular courses are delivered during the two main terms, Fall and Winter Term, that start the second half of September and early January, respectively (and each of them has a duration of 12 weeks). Each of these courses worth 3 credits. We also schedule special courses, invited lecture series or seminars beyond these two terms, especially during the Spring Term.

Graduation Requirements

The distribution of **credits required for graduation** is shown in the following table:

Total (a + b)	60 credits
a. Coursework	**45 credits**
• Mandatory Courses	18 credits
• Elective Courses	27 credits
b. Research + Thesis	**5 + 10 = 15 credits**

The 5 research credits mentioned in the above table are obtained as follows.

- First Year: the Winter MS Seminar (Pass/Fail), 1 credit,
- First Year: the Spring MS Seminar (Pass/Fail), 1 credit,
- Second Year: the Winter MS Seminar (Pass/Fail), 2 credits
- Second Year: the MS thesis proposal, 1 credit.

Mandatory courses are listed in this Handbook below, and the list of elective courses is contained in a separate file together with syllabi of both mandatory and elective courses. Students are allowed to take 4 credits per Academic Year for grade in any subject offered by an academic unit at CEU, and the rest of the course credits should be mathematics related with the approval of the MS Program Director.

The minimum passing grade for every exam, including thesis, is C+ (worth 2.33). Course grades count towards the final Grade Point Average (GPA) as per credit and constitute 75% of the final GPA. More precisely, the

$$\textbf{Final GPA} = \textbf{0.75} \times \textstyle\sum \textbf{n}_{\textbf{i}}\textbf{g}_{\textbf{i}} / \sum \textbf{n}_{\textbf{i}} + \textbf{0.25} \times \textbf{thesis grade},$$

where $\textbf{n}_{\textbf{i}}$ represents the number of credits attributed to course $\textbf{c}_{\textbf{i}}$ and $\textbf{g}_{\textbf{i}}$ is the grade obtained in the corresponding exam.

The minimum final GPA required for the M.S. degree is 2.67. Note that our university uses the US credit system.

All MS students are required to take the Latex for Mathematicians course in the First Year, and the Thesis Writing course in the Second Year, as a preparation for their thesis.

All MS students are required to attend the Winter MS Seminar, which aims to introduce students to various topics in mathematics and its applications, and facilitate their research work toward the MS Thesis (see Section *Thesis* below).Students are expected to give a talk, or to prepare the notes, possible in a group, about a talk given at the Winter MS Seminar.

First year MS students are required to attend the Spring MS Seminar, which prepares them to do independent work on understanding a topic.

In addition, all MS students are required to attend the Departmental Colloquiums, where they learn about important areas of Mathematics and its Applications.

Second year MS students are required to write a preliminary thesis proposal of 3-5 pages.

As a final condition for graduation, MS students are required to write a thesis (worth 10 credits) which is defended by the end of the program. The thesis must be submitted 3 weeks before the defense. The defense comprises the presentation of the thesis as well as a comprehensive exam on the area of the thesis, covering the material of 3 courses, including at least 2 electives (either 3 electives or 2 electives + 1mandatory).

Specific assessment methods, including specific homework assignments, computer simulations, classroom presentations on various topics, etc. may be required by instructors, depending on the nature of the course.

For general CEU regulations, visit:
https://www.ceu.edu/sites/default/files/attachment/basic_page/132/p-1105-2-v1211-student-rights-policyfinal.pdf, *Student Rights, Rules, and Academic Regulations*. This includes in particular standards and assessment techniques.

Remark. Our M.S. program is in line with the standards of the European Union, taking into account that **1 CEU credit = 2 ECTS credits**.

Courses

Students are required to earn a total of 45 course credits, out of which (at least) 24 credits should be taken in the first year, including all the mandatory courses M1-M7 (see the list in Annex 1, and the syllabi in the attached file about MS courses). The remaining necessary course credits are taken in the second year. Note that each M.S. regular course has 3 credits (1 credit = 12 x 50 minutes = 600 teaching minutes).

We offer tutorial help to first year M.S. students meet the level required by the program.

To acquire enough general information, among the 45 course credits, students are encouraged to earn some credits in courses from other CEU departments. They are also allowed to take some Ph.D. courses, with and only with the consent of their advisors and the instructors of the corresponding courses. Such Ph.D. courses are counted as M.S. elective courses, with the same number of credits.

Credits earned by courses taken at another university during the Second year of study may count upon the approval of the MS Program Director, and subject to the credit transfer policy of CEU.

Grading criteria for the courses

- problem solving skills
- understanding and being able to apply the theory
- understanding the fundamental questions in the field of the course

Thesis

Every MS Student chooses an advisor at the end of the first year when her/his interests become more specific. Typically faculty members serve as advisers.

MS students are required to write a thesis on a topic related to the specific area of specialization, under close supervision. The thesis may survey theoretical mathematical topics or mathematical topics related to other Sciences or real world applications, possibly including original results. In any case, the point of view of the thesis, and the formulation and description of the known results have to be original, copy-paste from other people's work is unacceptable.

Typically, an MS student completes her/his coursework in two years, prepares the thesis during the second year, and defends it by the end of the second year. However, according to the general CEU rules, the thesis may be submitted within a maximum of two years of finishing the coursework of the program. Additional courses may be offered to some of the students, beyond the first two years of studies, in order to help them write a good thesis and get better prepared in their area of interest.

Besides close and specialized supervision, students can benefit from workshops, seminars, summer schools.

Typically, the thesis is defended by the end of the student's second year. The thesis must be submitted 3 weeks in advance. The defense comprises the presentation of the thesis as well as a comprehensive exam on the area of the thesis, covering the material of 3 courses, including at least 2 electives (i.e., either 3 electives or 2 electives + 1 mandatory).

Grading criteria for MS theses

A,A-,B+,B,B-,C+ or fail

The grade should reflect the mathematical maturity of the thesis, the attitude, and the level of the required skills. The following are the key components that should be measured: novelty, comprehensiveness, coherence, correctness, language. If the thesis fails at least at one part then the thesis should fail. Otherwise the grade should reflect the average of the grades on the five components.. The measurements according to the certain criteria are suggestions only, they serve as a guideline for the evaluation.

1)Novelty (Measuring Program Learning Outcomes related to Knowledge)
A : Something original (it can be an original connection, too) is contained

B : Though not recent, it describes something that was alive within 50 years

C+: The material is introductory course level
fail: the material barely goes beyond the high school level

2)Comprehensiveness (Measuring Program Learning Outcomes related to Knowledge)
A : It does not miss any important aspect of the topic of the thesis

B : It does miss aspects from its focus, but mentions several key aspects

C+: It treats some aspects of the focus
fail: It has no focus or even there it misses almost everything

3)Coherence (Measuring Program Learning Outcomes related to Skills)
A : The thesis is well built, it is developed carefully, the notation is consistent and clear

B : The thesis is not well organized, but with difficulties it is readable

C+: Parts of the thesis are almost unintelligible but some are manageable
fail: It is obscure, almost fully unintelligible

4)Correctness (Measuring Program Learning Outcomes related to Attitudes)
A : There are no mistakes in the arguments

B : There is a mistake that cannot be repaired by simple means

C+: There are some obviously false claims or arguments
fail: At least the quarter of the thesis is incorrect beyond repair

5)Language (Measuring Program Learning Outcomes related to Skills)
A : The English of the thesis is generally correct

B : The readability of the thesis is questionable at certain parts

C+: The majority of the thesis is readable but the language is flawed throughout
fail: The majority of the thesis is (almost) unreadable

Mandatory Courses

First Year, Fall term

M1. Basic Algebra 1

M2. Real Analysis

M3. Probability

First Year, Winter term

M4. Basic Algebra 2

M5. Complex Function Theory

M6. Functional Analysis and Differential Equations

ANNEX 2(Prerequisites for the Entrance Exam)

Algebra

Linear Algebra:

- Vector spaces over **R**, **C**, and other fields: subspaces, linear independence, basis and dimension.
- Linear transformations and matrices: constructing matrices of abstract linear transformations, similarity, change of basis, trace, determinants, kernel, image, dimension theorems, rank; application to systems of linear equations.
- Eigenvalues and eigenvectors: computation, diagonalization, characteristic and minimal polynomials, invariance of trace and determinant.
- Inner product spaces: real and Hermitian inner products, orthonormal bases, Gram-Schmidt orthogonalization, orthogonal and unitary transformations, symmetric and Hermitian matrices, quadratic forms.

Abstract Algebra:

- Groups: finite groups, matrix groups, symmetry groups, examples of groups (symmetric, alternating, dihedral), normal subgroups and quotient groups, homomorphisms, Sylow theorems.
- Rings: ring of integers, induction and well ordering, polynomial rings, roots and irreducibility, unique factorization of integers and polynomials, homomorphisms, ideals, principal ideals, Euclidean domains, prime and maximal ideals, quotients, fraction fields, finite fields.

Analysis

- Real numbers as a complete ordered field. Extended real number system. Topological concepts: neighborhood, interior point, accumulation point, etc.
- Sequences of real numbers. Convergent sequences. Subsequences. Fundamental results.
- Numerical series. Standard tests for convergence and divergence.
- Real functions of one real variable. Limits, continuity, uniform continuity, differentiation, Riemann integration, fundamental theorem of calculus, mean value theorem, L'Hopital's rule, Taylor's theorem, etc. Sequences and series of functions. Pointwise and uniform convergence. Fundamental results. Power series and radii of convergence.
- The topology of $\mathbf{R}^k$. Connected and convex subsets of $\mathbf{R}^k$.
- Functions of several real variables. Limits, continuity, uniform continuity. Continuous functions on compact or connected sets. Partial derivatives. Differentiable functions. Taylor's theorem. Maxima and minima. Implicit and inverse function theorems.
- Multiple integrals. Integrals in various coordinate systems. Vector fields in Euclidean space (divergence, curl, conservative fields), line and surface integrals, vector calculus (Green's theorem in the plane, the divergence theorem in 3-space).
- Ordinary differential equations. Elementary techniques for solving special differential equations (separable, homogeneous, first order linear, Bernoulli's, exact, etc.). Existence and uniqueness of solutions to initial value problems (Picard's theorem). Linear differential equations and systems. Fundamental results.