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# Appendices for the Master's degree programme(s) in Applied Mathematics

## 2023-2024

# Appendix I Learning outcomes of the degree programme (art. 3.1)

**Objective of MSc Applied Mathematics**
As a consequence of the ongoing automation of society and the technological innovations that go along with it, the call of our society for mathematics is growing. Underneath virtually every form of automation lies a mathematical concept or model. In order to be able to respond to this development in society, it is important that mathematics is utilized in a proper and effective way. This requires that society has access to sufficiently many well qualified and highly trained mathematicians. The master's degree programme in Applied Mathematics aims to train mathematicians who meet this profile.

The master's degree programme in Applied Mathematics aims to impart knowledge, skills, understanding and an academic attitude in the field of mathematics by means of a broadly based curriculum building on a bachelor's degree in Applied Mathematics, such that Master's graduates are able to pursue an independent career as independent professionals and are also qualified for further training to become academic researchers or designer in the field.

**Learning outcomes MSc Applied Mathematics**
The above objective has been translated into a set of learning outcomes for the programme. The learning outcomes consist of general learning outcomes with respect to both knowledge and skills (which are applicable for the Master's degree programme in Mathematics as well) which are supplemented with programme-specific learning outcomes. For each learning outcome a reference to the Dublin descriptors is given between brackets.

The master graduate in Applied Mathematics:

A1. has an understanding of the most important concepts of the field, [applying knowledge and understanding]
A2. is able to contribute to the scientific advancement of a subfield of applied mathematics, [applying knowledge and understanding]
A3. is able to use abstract thinking and mathematical modelling to get to the root of a problem and thus recognize whether existing methods are applicable, or to ascertain that new methods must be developed, [applying knowledge and understanding]
A4. is able to function in multidisciplinary teams, [applying knowledge and understanding]
A5. is familiar with the social and ethical aspects of applying mathematics in practice, [judgement]
A6. understands the scientific relevance of problem definitions and results, and the validity of the scientific method, [judgement]
A7. is able to communicate effectively ideas, problems and solutions with the mathematical, science and engineering communities. [communication]
A8. is able to express him- or herself well both orally and in writing, [communication]
A9. is able to evaluate the scientific literature so as to keep their knowledge up to date. [learning]

In addition, the master graduate in Applied Mathematics:

T1. has general knowledge of the theories, methods and techniques in the field of applied mathematics, [knowledge and understanding]
T2. has specialized knowledge in at least one of the following subfields of applied mathematics: [knowledge and understanding]
    a. Computational Mathematics
    b. Systems, Control and Optimization
    c. Statistics
T3. has wide experience with the mathematical modelling of problems from actual practice, [applying knowledge and understanding]
T4. has extensive experience with using the relevant mathematical tools. [applying knowledge and understanding]

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# Appendix II Tracks/Specializations of the degree programme (art. 3.6)

The degree programme has the following specializations

1. Computational Mathematics
2. Systems and Optimization
3. Statistics and Data Science

# Appendix III Content of the degree programme (art. 3.8)

The Master's degree programme in Applied Mathematics has a workload of at least 120 ECTS and it should not be possible to remove 1 course and still have more than 120 ECTS. The Master's programme comprises a compulsory specialization independent course set with a workload of 65 ECTS and a specialization specific part.

**Compulsory joint programme**

| Course unit | Course code | ECTS | Practical | Entry requirements |
|---|---|---|---|---|
| Mathematics and its Environment | WMMA013-05 | 5 | | |
| Student Colloquium | WMMA029-05 | 5 | | |
| Research Seminar in Applied Mathematics | WMMA050-05 | 5 | | |
| Master's Research Project in Applied Mathematics | WMMA901-35 | 35 | | See Appendix V |
| Internship Applied Mathematics | WMMA001-15 | 15 | | See Appendix V |

**Specialization Computational Mathematics**
The Computational Mathematics programme is composed of compulsory course units (35 ECTS) and electives. The compulsory courses are listed below, the electives can be found in App. IV.

**Compulsory courses Computational Mathematics**

| Course unit | Course code | ECTS | Practical | Entry requirements |
|---|---|---|---|---|
| Computational Fluid Dynamics | WMMA012-05 | 5 | PR | |
| Iterative Algorithms | WMMA057-05 | 5 | | |
| Finite Element Methods and Applications | WMMA051-05 | 5 | PR | |
| Coupled Problems (24/25) | WMMA052-05 | 5 | PR | |
| Multiscale Numerical Methods (23/24) | WMMA054-05 | 5 | PR | |
| Model Reduction for PDE (24/25) | WMMA053-05 | 5 | | |
| Numerical Bifurcation Analysis (23/24) | WMMA055-05 | 5 | PR | |

**Specialization Systems and Optimization**
The Systems and Optimization programme is composed of compulsory course units (min. 40 ECTS) and electives. The compulsory courses are listed below, the electives can be found in App. IV.

**Compulsory courses Systems and Optimization**

| Course unit | Course code | ECTS | Practical | Entry requirements |
|---|---|---|---|---|
| Robust Control | WMMA021-05 | 5 | | |
| Convex Analysis (24/25) | WMMA060-05 | 5 | | |
| Iterative Algorithms | WMMA057-05 | 5 | | |
| Modeling and Identification (24/25) | WMMA007-05 | 5 | | |
| Modeling and Control of Complex Nonlinear Engineering Systems | WMMA020-05 | 5 | | |
| Calculus of Variations and Optimal Control | WMMA056-05 | 5 | | |
| Evolution Equations (23/24) | WMMA059-05 | 5 | | |
| Data-based Analysis and Control (23/24) | WMMA058-05 | 5 | | |
| Systems and Control (22/23, Mastermath) | WMMA003-06 | 6 | | |

**Specialization Statistics and Data Science**
The Statistics and Data Science programme is composed of compulsory course units (35 ECTS) and electives. The compulsory courses are listed below, the electives can be found in App. IV.

**Compulsory courses Statistics and Data Science**

| Course unit | Course code | ECTS | Practical | Entry requirements |
|---|---|---|---|---|
| Contemporary Statistics with Applications | WMMA015-05 | 5 | | |
| Statistical Genomics (23/24) | WMMA008-05 | 5 | | |
| Statistical Consulting (24/25) | WMMA024-05 | 5 | | |
| Introduction to Data Science | WMCS002-05 | 5 | | |
| One out of<br>– Statistical Signal Processing<br>– Fitting dynamical models to data | <br>WMAS011-05<br><br>WMIE007-05 | 5 | | |
| Topics in Probability and Statistics | WMMA039-05 | 5 | | |
| Mathematical modelling and statistical analysis of the spread of infectious diseases (23/24) | WMMA061-05 | 5 | | |

## Possibility of double master degrees

It is possible to study the MSc Applied Mathematics in parallel to other master programmes. Individual courses can then count for both programmes, however in order to obtain two degrees at least 180 distinct ECTS have to be obtained. Furthermore, an internship/design project as well as a master research project can only be used for one of the degree programmes, unless the Board of Examiners allows a joint internship or research project.

# Appendix IV Electives (art. 3.9.1)

This appendix sets out the optional course units of the Master's degree programme in Applied Mathematics. Based on a well-founded request by a student, the Board of Examiners may grant permission to choose electives other than those listed here (from the University of Groningen or another university in the Netherlands or abroad). The programme or a part of it must in any case be coherent and of master level (at the discretion of the Board of Examiners).

**External electives**

The Departments of Mathematics of the Dutch universities organise a joint Mastermath programme consisting of about 60 Master's courses; see http://elo.mastermath.nl for details. The degree programme may contain elective modules of Mastermath. Because the workload of these modules is not 5 ECTS, but 6 or 8 ECTS, it may be that the total size of the programme is not exactly equal to 120 ECTS. If so, the size must be at least 120 ECTS and it should not be possible to remove 1 course and still have more than 120 ECTS; hence the total workload of the degree programme can be at most 124 ECTS. Note, at the discretion of the Board of Examiners, courses may be added as extracurricular.

The degree programme in Applied Mathematics may also contain courses from other degree programmes. For information on the modules offered by other degree programmes at the University of Groningen, see also the Teaching and Examination Regulations of the corresponding programme.

**Specialization Computational Mathematics**
The electives in the track Computational Mathematics have a workload of 20-24 ECTS, of which 0-8 ECTS can be chosen freely (modules on Master level, relevant for Applied Mathematics, at the discretion of the Board of Examiners), the remaining electives must be chosen from the list below.

**Guided Choice Computational Mathematics**

| Course unit | Course code | ECTS | Practical | Entry requirements |
|---|---|---|---|---|
| Computational Solid Mechanics | WMME028-05 | 5 | | |
| Machine Learning | WMAI010-05 | 5 | | |
| Neural Networks and Computational Intelligence | WMCS010-05 | 5 | | |
| Introduction to Data Science | WMCS002-05 | 5 | | |
| Image Processing | WMCS008-05 | 5 | | |
| Scalable Computing | WMCS017-05 | 5 | | |
| Fitting Dynamical Models to Data | WMIE007-05 | 5 | | |
| Relevant courses from the Mastermath programme<br>(at the discretion of the Board of Examiners).<br>The Mastermath courses mentioned below are certainly relevant. | | 6/8 | | |
| Numerical Linear Algebra (Mastermath) | WMMA002-08 | 8 | | |
| Parallel Algorithms (Mastermath) | | 8 | | |
| Discrete Optimization (Mastermath) | | 6 | | |
| Inverse Problems in Imaging (Mastermath) | | 6 | | |
| Contemporary Statistics with Applications | WMMA015-05 | 5 | | |
| Statistical Consulting (24/25) | WMMA024-05 | 5 | | |
| Modelling and Control of Complex Nonlinear Engineering Systems | WMMA020-05 | 5 | | |
| Data-driven Optimization | WMME011-05 | 5 | | |
| Robust Control | WMMA021-05 | 5 | | |
| Modeling and Identification (24/25) | WMMA007-05 | 5 | | |
| Data-based Analysis and Control (23/24) | WMMA058-05 | 5 | | |
| Can only be followed together:<br>- Basiscursus Master Lerarenopleiding (Dutch)<br>- Masterstage 1 (Dutch) | <br>TEM0105<br>TEM0205 | <br>5<br>5 | | |

Note: The two last courses offer students the possibility to get acquainted with the work of a high school Mathematics teacher in the Netherlands. The courses are taught in Dutch and have

to be followed simultaneously. Upon successful completion of both courses students have the possibility to follow the post-master degree programme 'Leraar Voorbereidend Hoger Onderwijs in de Betawetenschappen' (LVHO) where they only still have to follow 50 ECTS, instead of the normal 60 ECTS.

**Specialization Systems and Optimization**

The electives in the specialization Systems and Optimization have a workload of 9-18 ECTS, of which 0-8 ECTS can be chosen freely (modules on Master level, relevant for Applied Mathematics, at the discretion of the Board of Examiners), the remaining elective(s) must be chosen from the list below.

**Guided Choice Systems and Optimization**

| Course unit | Course code | ECTS | Practical | Entry requirements |
|---|---|---|---|---|
| Analysis and Control of Smart Systems | WMIE015-05 | 5 | | |
| Robotics for IEM | WMIE005-05 | 5 | | |
| Advanced Digital and Hybrid Control Systems | WMIE014-05 | 5 | | |
| Data-driven Optimization | WMME011-05 | 5 | | |
| Computational Fluid Dynamics | WMMA012-05 | 5 | | |
| Finite Element Methods and Applications | WMMA051-05 | 5 | | |
| Introduction to Data Science | WMCS002-05 | 5 | | |
| Contemporary Statistics with Applications | WMMA015-05 | 5 | | |
| Statistical Consulting (24/25) | WMMA024-05 | 5 | | |
| Fitting Dynamical Models to Data | WMIE007-05 | 5 | | |
| Relevant courses from the Mastermath programme<br>(at the discretion of the Board of Examiners) | | 6/8 | | |
| Can only be followed together:<br>- Basiscursus Master Lerarenopleiding (Dutch)<br>- Masterstage 1 (Dutch) | <br>TEM0105<br>TEM0205 | <br>5<br>5 | | |

**Specialization Statistics and Data Science**
The electives in the specialization Statistics and Data Science have a workload of 20-24 ECTS, of which 0-8 ECTS can be chosen freely (modules on Master level, relevant for Applied Mathematics, at the discretion of the Board of Examiners), the remaining electives must be chosen from the list below.

**Guided Choice Statistics and Data Science**

| Course unit | Course code | ECTS | Practical | Entry requirements |
|---|---|---|---|---|
| Pattern Recognition | WMCS011-05 | 5 | | |
| Machine Learning | WMAI010-05 | 5 | | |
| Neural Networks and Computational Intelligence | WMCS010-05 | 5 | | |
| Cloud Computing and Cloud-based Applications | WMCS032-05 | 5 | | |
| Astronomical Data Science | WMAS007-05 | 5 | | |
| Statistical Signal Processing | WMAS011-05 | 5 | | |
| Fitting dynamical models to data | WMIE007-05 | 5 | | |
| Big Data & Applications in Biomedicine | WMBM025-05 | 5 | | |
| Data Science in Biomedicine | WMBM023-05 | 5 | | |
| Robust Control | WMMA021-05 | 5 | | |
| Computational Fluid Dynamics | WMMA012-05 | 5 | | |
| Modeling and Control of Complex Nonlinear Engineering Systems | WMMA020-05 | 5 | | |
| Finite Element Methods and Applications | WMMA051-05 | 5 | | |
| Data-based Analysis and Control (23/24) | WMMA058-05 | 5 | | |
| Data-driven Optimization | WMME011-05 | 5 | | |
| Relevant courses from the Mastermath programme (at the discretion of the Board of Examiners) | | 6/8 | | |
| Can only be followed together:<br>- Basiscursus Master Lerarenopleiding (Dutch)<br>Masterstage 1 (Dutch) | TEM0105<br><br><br>TEM0205 | 5<br><br><br>5 | | |

# Appendix V Entry requirements and compulsory order of examinations (art. 4.4)

| Course unit | ECTS | Entry requirements |
|---|---|---|
| Master's Research Project Applied Mathematics | 35 | - Successful completion of 35 ECTS of modules of the Master's degree programme in Applied Mathematics<br>- Enrolment in progress for the research project course<br>- Approval of research plan including project schedule by supervisors and Master Project coordinator. |
| Internship Applied Mathematics | 15 | - Successful completion of 35 ECTS of modules of the Master's degree programme in Applied Mathematics<br>- Enrolment in progress for the internship<br>- Approval of internship including schedule by supervisors and the Internship coordinator. |

# Appendix VI Admission to the degree programme (art. 2.1A.1 + 2.1B.1)

Holders of the following Bachelor's degrees from the University of Groningen are considered to have sufficient knowledge and skills and will be admitted to the master's degree programme in Applied Mathematics:

- BSc Mathematics
- BSc Applied Mathematics

The above degrees from other Dutch universities are considered equivalent to the corresponding UG degrees.

# Appendix VII Transitional provisions (art. 7.1)

Since the TER for this academic year is applicable to all students registered in the Master's degree programme in Applied Mathematics, regardless of the starting date of students, transitional arrangements are in place.

In 2023/24 the tracks Computational Mathematics and Systems and Control are discontinued. Students who were enrolled in these tracks can finish these tracks according to the TER MSc Applied Mathematics 2022/23**.**

The 2022/23 curriculum has more and other compulsory course units than before. Therefore, a transitional arrangement applies to the cohort 2021/22 and earlier. Students from the cohort 2021/22 and earlier may replace the newly introduced, compulsory courses Student Colloquium and Research Seminar in Applied Mathematics by the discontinued courses Mathematical Modelling Colloquium (WMMA023-05) and Complexity and Networks (WMMA005-05), respectively, provided the discontinued courses have been completed before September 1, 2022. The transitional arrangements for the track-specific parts of the degree programme can be found below.

**For cohort 2021-2022 and earlier, Track Computational Mathematics**

For cohort 2021-2022 and earlier, the track-specific part of the Computational Mathematics programme is composed of compulsory course units (min 23 ECTS), a guided choice (min 15 ECTS) and electives (max 15 ECTS) that can be chosen freely (modules on Master level, relevant for Applied Mathematics, at the discretion of the Board of Examiners). The guided choice is to be taken from the list of electives in App. IV (Computational Math), or the list of electives in App IV (Computational Math) of the TER 2020-2021. The compulsory part is described below.

**Compulsory courses Computational Mathematics cohort 2020-2021 and earlier**

| Course unit | Course code | ECTS | Practical | Entry requirements |
|---|---|---|---|---|
| ≥ 23 ECTS out of: | | | | |
| - Computational Fluid Dynamics | WMMA012-05 | 5 | PR | |
| - Finite Element Methods and Applications | WMMA051-05 | 5 | PR | |
| - Computational Solid Mechanics | WMME028-05 | 5 | PR | |
| - Iterative Algorithms | WMMA057-05 | 5 | PR | |
| - Coupled Problems (24/25) | WMMA052-05 | 5 | PR | |
| - Multiscale Numerical Methods (23/24) | WMMA054-05 | 5 | PR | |
| - Numerical Bifurcation Analysis (23/23) *or* | WMMA055-05 | 5 | PR | |
| Numerical Bifurcation Analysis of Large-Scale Systems (Mastermath) | WMMA014-08 | 8 | PR | |

| | | | | |
|---|---|---|---|---|
| - Numerical Linear Algebra (Mastermath)<br>- Relevant courses from Mastermath (at the discretion of the Board of Examiners)<br><br>Min. 3 courses have to be local non-Mastermath courses | WMMA002-08 | 8<br><br>6/8 | PR | |

**For cohort 2021-2022 and earlier, Track Systems and Control**

For cohort 2021-2022 and earlier, the track-specific part of the Systems and Control programme is composed of compulsory course units (min 23 ECTS), a guided choice (min 15 ECTS) and electives (max 15 ECTS) that can be chosen freely (modules on Master level, relevant for Applied Mathematics, at the discretion of the Board of Examiners). The guided choice is to be taken from the list of electives in App. IV (Systems and Control), or the list of electives in App IV (Systems and Control) of the TER 2020-2021. The compulsory part is described below.

**Compulsory courses Systems and Control cohort 2020-2021 and earlier**

| Course unit | Course code | ECTS | Practical | Entry requirements |
|---|---|---|---|---|
| ≥ 23 ECTS out of: | | | | |
| - Robust Control | WMMA021-05 | 5 | | |
| - Convex Analysis | WMMA060-05 | 5 | | |
| - Modeling and Identification (24/25) | WMMA007-05 | 5 | | |
| - Modeling and Control of Complex Nonlinear Engineering Systems | WMMA020-05 | 5 | | |
| - Systems and Control (22/23, Mastermath) | WMMA003-06 | 6 | | |
| - Iterative Algorithms | WMMA057-05 | 5 | | |
| - Calculus of Variations and Optimal Control | WMMA056-05 | 5 | | |
| - Evolution Equations | WMMA059-05 | 5 | | |
| - Data-based Analysis and Control (23/24) | WMMA058-05 | 5 | | |
| - Relevant courses from Mastermath (at the discretion of the Board of Examiners)<br><br>Min. 3 courses have to be local non-Mastermath courses | | 6/8 | | |

The transitional provisions below are an arrangement that students can use as a reference to courses that previously existed.

**For cohort 2021-2022 and earlier**

| Old Course | New Course |
|---|---|
| Mathematical Modelling Colloquium | Student Colloquium |
| Complexity and Networks | Research Seminar in Applied Mathematics |
| Finite Element Methods for Fluid Dynamics | Finite Element Methods and Applications |
| Convex Optimization | Convex Analysis |
| Finite Element Modelling for Advanced Processing | Computational Solid Mechanics |
| Caput Statistics | Topics in Probability and Statistics |

See also the transitional arrangements in the appendices TER of previous years.
For information on transitional arrangements for courses offered by other degree programmes, see also the Teaching and Examination Regulations of the corresponding programme.

# Appendix VIII Additional Requirements Open Degree Programmes (Art. 3.10)

In exceptional circumstances, students wishing to pursue an open degree programme may file a request with the Board of Examiners. An Open Degree Programme must always be approved in advance by the Board of Examiners. The Board of Examiners will evaluate whether the proposed curriculum meets the learning outcomes of the degree programme and can determine further conditions in their rules and regulations.

The Open Degree Programme in Applied Mathematics must include the compulsory joint programme mentioned in App. III and at least 35 ECTS is to be taken from the lists of compulsory courses of the specializations, see App. III for details.