

Mathematical Sciences, B.S.

The Department offers five B.S. degrees. Students may choose a B.S. in Mathematical Sciences (p.), or a B.S. in Mathematical Sciences with one of the following concentrations.

- Operations Research and Statistics (p.)
- Statistics (p.)
- Discrete Mathematics & Logic (p.)
- Computational and Applied Mathematics (p.)

Each concentration has a list of required courses, along with electives. Any exceptions to the elective requirements require prior approval from the student's academic advisor. For each concentration, a suggested schedule that includes general education requirements can be found here (<https://www.cmu.edu/math/undergrad/degrees.html>). For a list of courses required for all Mellon College of Science students, see the MCS General Education Requirements (<http://coursecatalog.web.cmu.edu/schools-colleges/melloncollegeofscience/#generaleducationrequirementstext>).

A student preparing for graduate study should consider undertaking independent work. The Department offers 21-410 Research Topics in Mathematical Sciences and 21-599 Undergraduate Reading and Research for this purpose. At most, nine units of 21-410 or 21-599 credit can be applied toward depth elective requirements, and to do so requires prior approval from the student's academic advisor. Other opportunities for mathematical research can be found here (<https://www.cmu.edu/math/undergrad/research.html>).

Courses numbered 21-600 and above carry graduate credit, with courses at the 600-level designed as transitional courses to graduate study.

By default, students must fulfill all of the requirements of the catalog of the year they entered CMU. Students who wish to be considered for a subsequent catalog may submit a request to their academic advisor.

Additional Major Requirements

All concentrations within the B.S. in Mathematical Sciences are available as an additional major to students majoring in other departments. **The requirements for the additional majors are the same as those for the B.S. degrees, except that the MCS General Education requirements are waived, along with the requirement to take 21-201.** In order to avoid double-counting issues, students are encouraged to consult with their academic advisor for their primary degree as well as their additional major advisor. Please visit the Department of Mathematical Sciences Undergraduate FAQ website (<https://www.cmu.edu/math/undergrad/faq.html>) (under "Admissions") for further details.

B.S. in Mathematical Sciences

Overview

This program is the most flexible available to our majors. Students choose eight electives within the major and at least seven free electives, giving them the opportunity to design a program to suit their individual interests and goals.

Curriculum

The requirements for the B.S. in Mathematical Sciences are:

Mathematical Sciences Courses (required)

The alternative courses 21-242, 21-261, and 21-268 (or 21-269) are particularly recommended for a student planning to pursue graduate work.

	Units
21-120 Differential and Integral Calculus	10
21-122 Integration and Approximation	10
21-127 Concepts of Mathematics	12
or 21-128 Mathematical Concepts and Proofs	
21-201 Undergraduate Colloquium	1
21-228 Discrete Mathematics	9-12
or 15-251 Great Ideas in Theoretical Computer Science	
21-241 Matrices and Linear Transformations	11
or 21-242 Matrix Theory	
21-259 Calculus in Three Dimensions	10-12
or 21-266 Vector Calculus using Matrix Algebra	
or 21-268 Multidimensional Calculus	

or 21-269	Vector Analysis	
21-260	Differential Equations	9-10
or 21-261	Introduction to Ordinary Differential Equations	
or 33-231	Physical Analysis	
21-325	Probability	9-12
or 21-425	Probability and Martingales	
or 15-259	Probability and Computing	
or 36-218	Probability Theory for Computer Scientists	
21-341	Linear Algebra	9
or 21-374	Field Theory	
21-355	Principles of Real Analysis I	9-12
or 21-455	Intermediate Real Analysis I	
21-356	Principles of Real Analysis II	9-10
or 21-456	Intermediate Real Analysis II	
21-373	Algebraic Structures	9
		117-130

Computer Science Courses (required)

	Units
15-110 Principles of Computing	10-12
or 15-112 Fundamentals of Programming and Computer Science	
or 02-120 Programming for Scientists	
or 15-104 Introduction to Computing for Creative Practice	
	10-12

DEPTH ELECTIVES (REQUIRED)

Seventy-two total units

- **Forty-five units** of Mathematical Sciences Electives (at the 21-300 level or above or 21-270 or 21-292). A full list of courses offered in Mathematical Sciences is here (<http://coursecatalog.web.cmu.edu/schools-colleges/melloncollegeofscience/departments/mathematicalsciences/#coursestextcontainer>).
- **Twenty-seven units** of Technical Electives. These may be Mathematical Sciences (at the 21-300 level or above or 21-270 or 21-292), or Computer Science (at the 15-200 level or above), or Physics (at the 33-300 level or above), or Statistics (must be at the 36-300 level or above and have at least 36-225 as a prerequisite) electives. These may also be technical courses with course codes 10-xxx (Machine Learning), 11-xxx (Learning Technologies Institute), or 07-xxx (SCS interdisciplinary), subject to department approval.

MCS General Education (required)

MCS humanities, social sciences, and science core. (114 units)

Minimum number of units required for degree: 360

B.S. in Mathematical Sciences (Operations Research and Statistics)

Overview

An operations research professional employs quantitative and computational skills toward enhancing the function of an organization or process. Students choosing this concentration will develop problem-solving abilities in mathematical and statistical modeling and computer-based simulation in areas such as network design, transportation scheduling, allocation of resources and optimization. In addition to courses in mathematics and statistics, a basic background in economics and accounting is included. Since problems in business and industry are often solved by teams, the curriculum typically includes group projects. Students choosing this concentration may not pursue an additional minor in Statistics in the Dietrich College of Humanities and Social Sciences.

Curriculum

The requirements for the concentration in Operations Research and Statistics are:

Mathematical Sciences Courses (required)

The alternative courses 21-242, 21-261, and 21-268 (or 21-269) are particularly recommended for a student planning to pursue graduate work.

Courses	Units
21-120 Differential and Integral Calculus	10
21-122 Integration and Approximation	10
21-127 Concepts of Mathematics	12
or 21-128 Mathematical Concepts and Proofs	
21-201 Undergraduate Colloquium	1
21-228 Discrete Mathematics	9-12
or 15-251 Great Ideas in Theoretical Computer Science	
21-241 Matrices and Linear Transformations	11
or 21-242 Matrix Theory	
21-259 Calculus in Three Dimensions	10-12
or 21-266 Vector Calculus using Matrix Algebra	
or 21-268 Multidimensional Calculus	
or 21-269 Vector Analysis	
21-260 Differential Equations	9-10
or 21-261 Introduction to Ordinary Differential Equations	
or 33-231 Physical Analysis	
21-292 Operations Research I	9
21-369 Numerical Methods	12
21-393 Operations Research II	9
102-108	

Statistics Courses (required)

Courses	Units
21-325 Probability	9-12
or 21-425 Probability and Martingales	
or 15-259 Probability and Computing	
or 36-218 Probability Theory for Computer Scientists	
36-226 Introduction to Statistical Inference	9
36-401 Modern Regression	9
36-402 Advanced Methods for Data Analysis	9
36-410 Introduction to Probability Modeling	9
45-48	

Economics, Business, and Computer Science Courses (required)

Courses	Units
15-110 Principles of Computing	10
or 15-104 Introduction to Computing for Creative Practice	
or 15-112 Fundamentals of Programming and Computer Science	
or 02-120 Programming for Scientists	
70-122 Introduction to Accounting	9
73-102 Principles of Microeconomics	9
73-103 Principles of Macroeconomics	9
73-230 Intermediate Microeconomics	9
or 73-240 Intermediate Macroeconomics	
46	

Depth Electives (required)

Forty-five units of depth electives. These electives may be any Mathematical Sciences Elective (at the 21-300 level or above or 21-270) or courses chosen from the list below. **At least nine of these units must be Mathematical Sciences Electives (21-XXX).**

Courses	Units
21-3xx Mathematical Sciences	9-12
21-4xx Mathematical Sciences	9-12
10-301 Introduction to Machine Learning	12
or 07-280 Artificial Intelligence and Machine Learning I	
15-122 Principles of Imperative Computation	12
15-150 Principles of Functional Programming	12
15-210 Parallel and Sequential Data Structures and Algorithms	12
36-46X Special Topics (Statistics)	9-12

36-47X	Special Topics (Statistics)	9-12
70-371	Operations Management	9
70-460	Mathematical Models for Consulting	9
70-469	End to End Business Analytics	9
70-471	Supply Chain Management	9

MCS General Education (required)

MCS humanities, social sciences, and science core (114 units)

Note that 73-102, 73-103, 73-230, and 73-240 satisfy Nontechnical Elective (<http://coursecatalog.web.cmu.edu/schools-colleges/melloncollegeofscience/#generaleducationrequirements>) requirements from the MCS general education core.

Minimum number of units required for degree: **360**

B.S. in Mathematical Sciences (Statistics)**Overview**

Statistics is concerned with the process by which inferences are made from data. Statistical methods are essential to research in a wide variety of scientific disciplines. For example, principles of experimental design that assist chemists in improving their yields also help poultry farmers grow bigger chickens. Similarly, time series analysis is used to better understand radio waves from distant galaxies, hormone levels in the blood, and concentrations of pollutants in the atmosphere. This diversity of application is an exciting aspect of the field, and it is one reason for the current demand for well-trained statisticians.

The Statistics concentration is jointly administered by the Department of Mathematical Sciences and the Department of Statistics and Data Science. Students choosing this concentration may not pursue an additional minor in Statistics in the Dietrich College of Humanities and Social Sciences.

Curriculum

The requirements for the Statistics concentration are:

Mathematical Sciences Courses (required)

The alternative courses 21-242, 21-261, and 21-268 (or 21-269) are particularly recommended for a student planning to pursue graduate work.

Courses	Units
21-120 Differential and Integral Calculus	10
21-122 Integration and Approximation	10
21-127 Concepts of Mathematics	12
or 21-128 Mathematical Concepts and Proofs	
21-201 Undergraduate Colloquium	1
21-228 Discrete Mathematics	9-12
or 15-251 Great Ideas in Theoretical Computer Science	
21-241 Matrices and Linear Transformations	11
or 21-242 Matrix Theory	
21-259 Calculus in Three Dimensions	10-12
or 21-266 Vector Calculus using Matrix Algebra	
or 21-268 Multidimensional Calculus	
or 21-269 Vector Analysis	
21-260 Differential Equations	9-10
or 21-261 Introduction to Ordinary Differential Equations	
or 33-231 Physical Analysis	
21-292 Operations Research I	9
21-369 Numerical Methods	12
21-393 Operations Research II	9
102-108	

Statistics Courses (required)

Courses	Units
21-325 Probability	9-12
or 21-425 Probability and Martingales	
or 15-259 Probability and Computing	

or 36-218	Probability Theory for Computer Scientists	
36-226	Introduction to Statistical Inference	9
36-315	Statistical Graphics and Visualization	9
or 36-350	Statistical Computing	
36-401	Modern Regression	9
36-402	Advanced Methods for Data Analysis	9
36-410	Introduction to Probability Modeling	9
		54-57

Economics and Computer Science Courses (required)

Courses		Units
15-112	Fundamentals of Programming and Computer Science	12
or 02-120	Programming for Scientists	
15-122	Principles of Imperative Computation	12
73-102	Principles of Microeconomics	9
		33

Depth Electives (required)

Forty-five units of depth electives. These electives may be any Mathematical Sciences Elective (at the 21-300 level or above or 21-270) or courses chosen from the list below. **At least nine of these units must be Mathematical Sciences Electives (21-XXX). At least nine of these units must be Statistics Electives (36-XXX)**

Courses		Units
21-3xx	Mathematical Sciences	9-12
21-4xx	Mathematical Sciences	9-12
10-301	Introduction to Machine Learning	12
or 07-280	Artificial Intelligence and Machine Learning I	
15-150	Principles of Functional Programming	12
15-210	Parallel and Sequential Data Structures and Algorithms	12
36-46X	Special Topics (Statistics)	9-12
36-47X	Special Topics (Statistics)	9-12

MCS General Education (required)

MCS humanities, social sciences, and science core (114 units)

Note that 73-102 satisfies a requirement from the MCS core.

Minimum number of units required for degree: **360**

B.S. in Mathematical Sciences (Discrete Mathematics and Logic)

Overview

Discrete mathematics is the study of finite and countable structures and algorithms for the manipulation and analysis of such structures, while mathematical logic is the study of axiomatic systems and their mathematical applications. Both are flourishing research areas and have close ties with computer science.

The Discrete Mathematics and Logic concentration provides a rigorous background in discrete mathematics and mathematical logic, together with the elements of theoretical computer science. It prepares the student to pursue research in these fields, or to apply their ideas in the many disciplines, ranging from philosophy to hardware verification, where such ideas have proved relevant.

Curriculum

The requirements for the Discrete Mathematics and Logic concentration are:

Mathematical Sciences and Computer Science Courses (required)

The alternative course 21-242 is particularly recommended for a student planning to pursue graduate work.

Courses		Units
15-122	Principles of Imperative Computation	12
15-150	Principles of Functional Programming	12
15-210	Parallel and Sequential Data Structures and Algorithms	12
21-120	Differential and Integral Calculus	10
21-122	Integration and Approximation	10
21-127	Concepts of Mathematics	12
or 21-128	Mathematical Concepts and Proofs	
21-201	Undergraduate Colloquium	1
21-228	Discrete Mathematics	9
or 21-301	Combinatorics	
21-241	Matrices and Linear Transformations	11
or 21-242	Matrix Theory	
21-300	Basic Logic	9
21-341	Linear Algebra	9
or 21-374	Field Theory	
21-355	Principles of Real Analysis I	9-12
or 21-455	Intermediate Real Analysis I	
21-373	Algebraic Structures	9
		125-128

Computer Science Electives (required)

Any two courses at the 300 level or above. The following are specifically suggested:

15-312	Foundations of Programming Languages	12
15-317	Constructive Logic	9
15-451	Algorithm Design and Analysis	12

Depth Electives (required)

Seventy-two units of depth electives, to be chosen from the two lists below, or any other Mathematical Sciences Elective (at the 21-300 level or above or 21-270 or 21-292). **At least thirty-six of these units must be Discrete Mathematics and Logic Electives (List 1).**

List 1 (Discrete Mathematics and Logic Electives)

Courses		Units
15-251	Great Ideas in Theoretical Computer Science	12
or 21-301	Combinatorics	
21-321	Interactive Theorem Proving	9
21-322	Topics in Formal Mathematics	9
21-325	Probability	9
or 21-425	Probability and Martingales	
or 15-259	Probability and Computing	
21-329	Set Theory	9
21-374	Field Theory	9
21-400	Intermediate Logic	9
21-441	Number Theory	9
21-484	Graph Theory	9
21-602	Introduction to Set Theory I	12
21-603	Model Theory I	12
21-610	Algebra I	12
21-701	Discrete Mathematics	12
80-305	Game Theory	9
or 80-405	Game Theory	
80-311	Undecidability and Incompleteness	9
80-411	Proof Theory	9
80-413	Category Theory	9

List 2 (Mathematics Electives)

Courses		Units
21-259	Calculus in Three Dimensions	10-12
or 21-266	Vector Calculus using Matrix Algebra	
or 21-268	Multidimensional Calculus	
or 21-269	Vector Analysis	
21-260	Differential Equations	9-10
or 21-261	Introduction to Ordinary Differential Equations	
or 33-231	Physical Analysis	

21-270	Introduction to Mathematical Finance	9
21-292	Operations Research I	9
21-3xx	Mathematical Sciences	9-12
21-4xx	Mathematical Sciences	9-12

MCS General Education (required)

MCS humanities, social sciences, and science core (114 units)

Minimum number of units required for degree: 360

B.S. in Mathematical Sciences (Computational and Applied Mathematics)

Overview

This concentration is designed to prepare students for careers in business or industry which require significant analytical, computational and problem solving skills. It also prepares students with interest in computational and applied mathematics for graduate school.

The students in this concentration develop skills to choose the right framework to quantify or model a problem, analyze it, simulate and in general use appropriate techniques for carrying the effort through to an effective solution. The free electives allow the student to develop an interest in a related area by completing a minor in another department, such as Engineering Studies, Economics, Information Systems or Business Administration.

Curriculum

The requirements for the Computational and Applied Mathematics concentration are:

Mathematical Sciences Courses (required)

The alternative courses 21-242, 21-261, and 21-268 (or 21-269) are particularly recommended for a student planning to pursue graduate work.

Courses		Units
21-120	Differential and Integral Calculus	10
21-122	Integration and Approximation	10
21-127	Concepts of Mathematics	12
or 21-128	Mathematical Concepts and Proofs	
21-201	Undergraduate Colloquium	1
21-228	Discrete Mathematics	9-12
or 15-251	Great Ideas in Theoretical Computer Science	
21-241	Matrices and Linear Transformations	11
or 21-242	Matrix Theory	
21-259	Calculus in Three Dimensions	10-12
or 21-266	Vector Calculus using Matrix Algebra	
or 21-268	Multidimensional Calculus	
or 21-269	Vector Analysis	
21-260	Differential Equations	9-10
or 21-261	Introduction to Ordinary Differential Equations	
or 33-231	Physical Analysis	
21-325	Probability	9-12
or 21-425	Probability and Martingales	
or 15-259	Probability and Computing	
or 36-218	Probability Theory for Computer Scientists	
21-355	Principles of Real Analysis I	9-12
or 21-455	Intermediate Real Analysis I	
21-369	Numerical Methods	12
21-469	Computational Introduction to Partial Differential Equations	12

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Computer Science Courses (required)

Courses		Units
15-112	Fundamentals of Programming and Computer Science	12

or 02-120 Programming for Scientists

15-122	Principles of Imperative Computation	12
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Depth Electives (required)

Sixty-three total units

- **Twenty-seven of these units** must be Computational and Applied Mathematics electives listed below.
- **Twenty-seven of these units** must be Mathematical Sciences Electives (at the 21-300 level or above or 21-270 or 21-292). These may include further Computational and Applied Mathematics electives.
- **Nine units** of Technical Electives. These may be Mathematical Sciences (at the 21-300 level or above or 21-270 or 21-292), or Computer Science (at the 15-200 level or above), or Physics (at the 33-300 level or above), or Statistics (must be at the 36-300 level or above and have at least 36-225 as a prerequisite) electives. These may also be technical courses with course codes 10-xxx (Machine Learning), 11-xxx (Learning Technologies Institute), or 07-xxx (SCS interdisciplinary), subject to department approval.

Computational and Applied Mathematics Electives

Courses		Units
10-301	Introduction to Machine Learning	12
or 07-280	Artificial Intelligence and Machine Learning I	
21-270	Introduction to Mathematical Finance	9
21-292	Operations Research I	9
21-326	Markov Chains: Theory, Simulation and Applications	9
21-344	Numerical Linear Algebra	9
21-380	Introduction to Mathematical Modeling	9

MCS General Education (required)

MCS humanities, social sciences, and science core (114 units).

Minimum number of units required for degree: 360