Department of Mathematical Sciences

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Location: Wean Hall 6113

www.math.cmu.edu (http://www.math.cmu.edu)

Mathematics provides much of the language and quantitative underpinnings of the natural and social sciences, and mathematical scientists have been responsible for the development of many of the most commonly used tools in business management as well as for laying the foundation for computational and computer science. The name of the Department of Mathematical Sciences reflects its tradition of outstanding research and teaching of applicable mathematics relating to these areas. Indeed, the Department contains highly ranked research groups in Applied Mathematics, Discrete Mathematics, Logic, and Mathematical Finance. These research strengths are reflected in the variety of options that the Department provides for its undergraduate majors.

The Department offers a B.S. degree in Mathematical Sciences. Concentrations within the degree include Mathematical Sciences, Operations Research and Statistics, Statistics, Discrete Mathematics and Logic, and Computational and Applied Mathematics.

The Mathematical Sciences concentration is the least structured of our programs, in recognition of the wide variety of interests that can be productively coupled with the study of mathematical sciences. It can be an appropriate choice for students planning for graduate study in mathematics or seeking to design their curriculum to take advantage of the many opportunities for a second major from another department in the University.

The Operations Research and Statistics concentration prepares students to enter the area of operations research. Mathematicians with a background in operations research are especially valuable in such diverse activities as project planning, production scheduling, market forecasting and finance. Such applications are found in virtually all industrial and governmental settings.

The Statistics concentration prepares students to contribute to a wide variety of research areas. Applications range from experimental design and data analysis in the physical and social sciences, medicine and engineering, to modeling and forecasting in business and government, to actuarial applications in the financial and insurance industries. This is also a useful second major for students planning for graduate study and research in subject areas requiring a strong statistical background.

The Discrete Mathematics and Logic concentration provides a background in discrete mathematics, mathematical logic, and theoretical computer science. This concentration prepares the student to do research in these and related fields, or to apply their ideas elsewhere.

Finally, the Computational and Applied Mathematics concentration provides the background needed to support the computational and mathematical analysis needs of a wide variety of businesses and industries and is well suited to students with an interest in the physical sciences and engineering.

The Department places great emphasis on the advising of students. This is critical if students are to make the most of their years at the University. Students are urged to work carefully with their advisor and other faculty to formulate their degree programs. Study abroad is encouraged, and an interested student should investigate the opportunities available in the Undergraduate Options (http://coursecatalog.web.cmu.edu/aboutcmu/undergraduateoptions/) section of the catalog.

Special Options

The Department offers special opportunities for the exceptionally well-prepared and intellectually ambitious student. These options are available to students from any department in the University.

Matrix Theory and Vector Analysis

For selected freshmen entering the University, the department offers the fall/spring sequence of 21-242 Matrix Theory and 21-269 Vector Analysis, which include a rigorous introduction to proofs and abstract mathematics. Typically, a student choosing this sequence has mastered the operational

aspects of high school mathematics and now seeks a deeper conceptual understanding.

- 21-242 Matrix Theory is an honors version of 21-241 Matrices and Linear Transformations .
- 21-269 Vector Analysis is an honors version of 21-268 Multidimensional Calculus

Admission to 21-242 Matrix Theory is based on an assessment exam taken at the start of the freshman year. Admission to 21-269 Vector Analysis is based on a student's performance in 21-242 Matrix Theory, and on other courses taken in the fall semester.

Mathematical Studies

The sequence of undergraduate honors courses continues with the Mathematical Studies courses, aimed primarily at sophomores. These highly demanding courses provide excellent preparation for graduate study, with many of the participants taking graduate courses as early as their junior year. Students will be expected to master material at a high level of abstraction, and to work on very challenging problems. The typical enrollment of about 15 students allows for close contact with the instructors.

- 21-235 Mathematical Studies Analysis I is an honors version of 21-355 Principles of Real Analysis I.
- 21-237 Mathematical Studies Algebra I is an honors version of 21-373 Algebraic Structures.
- 21-236 Mathematical Studies Analysis II is an honors version of 21-356 Principles of Real Analysis II.
- 21-238 Mathematical Studies Algebra II) is an honors version of 21-341 Linear Algebra.

Admission to Mathematical Studies is by invitation. Interested students should apply during the spring of their freshman year. Applicants are not absolutely required to have taken 21-242 Matrix Theory or 21-269 Vector Analysis, and may be admitted on the basis of exceptionally strong performance in non-honors mathematics courses.

It is possible to take only the algebra courses or only the analysis courses. Admission to 21-236 Mathematical Studies Analysis II requires a grade of B or better in 21-235 Mathematical Studies Analysis I, and similarly, admission to 21-238 Mathematical Studies Algebra II requires a grade of B or better in 21-237 Mathematical Studies Algebra I.

Interdisciplinary Programs

Several interdisciplinary options enable a student to combine mathematics with other disciplines.

- The Bachelor of Science and Arts (http:// coursecatalog.web.cmu.edu/intercollegeprograms/bxaintercollege/ #bachelorofscienceandartsdegreeprogram) program allows a student to combine mathematics with study in any of the five schools in the College of Fine Arts.
- The Bachelor of Science in Mathematics and Economics (http://coursecatalog.web.cmu.edu/schoolscolleges/tepper/undergraduateeconomicsprogram/ #bsineconomicsandmathematicalsciences) is a flexible program which allows students to develop depth in both fields of study. Note: for students whose home college is Dietrich College, this major is known as the Bachelor of Science in Economics and Mathematical Sciences.
- Finally, a joint program with the Heinz College of Public Policy and Management and the Tepper School of Business leads to the degree Bachelor of Science in Computational Finance (http://coursecatalog.web.cmu.edu/intercollegeprograms/ #bachelorofscienceincomputationalfinance).

Curriculum

For each concentration, we provide a list of the requirements and a suggested schedule that takes prerequisites into account. A Mathematical Sciences, Computer Science, Physics, Statistics Elective refers to any course from the Departments of Mathematical Sciences, Computer Science, Physics, or Statistics and Data Science, respectively, satisfying the following restrictions: a mathematical sciences course must be at the 21-300 level or above or 21-270 or 21-292, a computer science course must be at the 15-200 level or above, a physics course must be at the 33-300 level or

above, and a statistics course must be at the 36-300 level or above and have at least 36-225 as a prerequisite.

Exceptions to the elective requirements for each concentration of the B.S. degree in Mathematical Sciences require prior approval from the student's advisor.

A student preparing for graduate study should also 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 a total of nine units of 21-410/21-599 can be applied toward the Depth Elective requirement. This requires permission of both the advisor and the department.

Mathematical Sciences majors are required to complete an introductory computer science course, either 15-110 or 15-112. Students who plan to take further computer science courses must complete 15-112.

A Nontechnical Elective refers to a course in the Dietrich College, the College of Fine Arts or the Tepper School of Business. Noted exceptions are described on the Mellon College of Science website (https://www.cmu.edu/mcs/undergrad/advising/hss-finearts/). A course listed as an elective is a free elective with the only restriction that the maximum total of ROTC, StuCo, and Physical Education units that will be accepted for graduation is nine

For a list of courses required for all MCS students, see the MCS General Education Requirements (http://coursecatalog.web.cmu.edu/schools-colleges/melloncollegeofscience/#generaleducationrequirementstextcontainer).

B.S. in Mathematical Sciences

This program is the most flexible available to our majors. The flexibility to choose eight electives within the major plus seven humanities courses and seven free electives allows the student to design a program to suit his or her individual needs and interests. By default, students must fulfill all 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 the Director of Undergraduate Studies. The requirements 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 for Computer Scientists	
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 15-259	Probability and Computing	
or 36-218	Probability Theory for Computer Scientists	
21-341	Linear Algebra	9
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

Forty-five units of (required) Mathematical Sciences electives (at the 21-300 level or above or 21-270 or 21-292).

Twenty-seven units of (required) 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.

MCS General Education (required)

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

Mathematical Sciences Electives for Students Intending Graduate Studies

Students preparing for graduate study in mathematics should consider the following courses as Mathematical Sciences electives, choosing among them according to the desired area of graduate study. Exceptions to the elective requirements for each concentration of the B.S. degree in Mathematical Sciences require prior approval from the student's academic advisor.

Courses		Units
21-301	Combinatorics	9
21-360	Differential Geometry of Curves and Surfaces	9
21-371	Functions of a Complex Variable	9
21-374	Field Theory	9
21-441	Number Theory	9
21-465	Topology	9
21-470	Selected Topics in Analysis	9
21-476	Introduction to Dynamical Systems	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
21-620	Real Analysis	6
21-621	Introduction to Lebesgue Integration	6
21-630	Ordinary Differential Equations	12
21-632	Introduction to Differential Equations	12
21-640	Introduction to Functional Analysis	12
21-651	General Topology	12
21-660	Introduction to Numerical Analysis I	12
21-701	Discrete Mathematics	12
21-720	Measure and Integration	12
21-721	Probability	12
21-723	Advanced Real Analysis	12
21-737	Probabilistic Combinatorics	12
21-738	Extremal Combinatorics	12

Note that courses 21-600 and above carry graduate credit. Courses at the 600 level are designed as transitional courses to graduate study. A student preparing for graduate study should also consider undertaking independent work. The Department offers 21-410 Research Topics in Mathematical Sciences and 21-599 Undergraduate Reading and Research for this purpose.

Courses 21-700 and above can be used with the permission of both the advisor and the department.

Suggested Schedule for students without Advanced credit for 21-120 and 21-122

Freshman Year

Fall		Units
21-120	Differential and Integral Calculus	10
21-241	Matrices and Linear Transformations	11
or 21-242	Matrix Theory	
38-101	EUREKA!: Discovery and Its Impact	6
76-101	Interpretation and Argument	9
99-101	Core@CMU	3
XX-XXX	Technical Breadth Requirement	9
		48
Spring		48 Units
Spring 15-110	Principles of Computing	-
. 3	Principles of Computing Fundamentals of Programming and Computer Science	Units 10-12
15-110	, , ,	Units 10-12
15-110 or 15-112	Fundamentals of Programming and Computer Science	Units 10-12
15-110 or 15-112 21-127	Fundamentals of Programming and Computer Science Concepts of Mathematics	Units 10-12

XX-XXX	Nontechnical Elective	9	Minimum nu	imber of units required for degree:	360
		50-52			
Sophomore `	Year			d Schedule for Students with Advance 21-120 and 21-122	ed
Fall		Units			
21-201	Undergraduate Colloguium	1	Freshman Ye	ear	
21-228	Discrete Mathematics	9-12	Fall		Unit
or 15-251	Great Ideas in Theoretical Computer Science		21-241	Matrices and Linear Transformations	13
21-268	Multidimensional Calculus	11	or 21-242	Matrix Theory	
XX-XXX	Technical Breadth Requirement	9	21-127	Concepts of Mathematics	12
xx-xxx	Nontechnical Elective	9	or 21-128	Mathematical Concepts and Proofs	
XX-XXX	Free Elective	9	38-101	EUREKA!: Discovery and Its Impact	(
		48-51	76-101	Interpretation and Argument	9
			99-101	Core@CMU	3
Spring		Units	XX-XXX	Technical Breadth Requirements	ç
21-261	Introduction to Ordinary Differential Equations	10			50
21-373	Algebraic Structures	9	Continue		l lade
38-230	ENGAGE in Wellness: Looking Inward	1	Spring	Data da la casa Canana di an	Unit
XX-XXX	Technical Breadth Requirement	9	15-110	Principles of Computing	10-12
XX-XXX	Technical Breadth Requirement	9	or 15-112	Fundamentals of Programming and Computer Scien	
XX-XXX	Nontechnical Elective	9	21-228	Discrete Mathematics	9-12
		47	or 15-251		
			21-268	Multidimensional Calculus	11-12
Junior Year			or 21-269	Vector Analysis	
Fall		Units	XX-XXX	Nontechnical Elective	g
21-355	Principles of Real Analysis I	9-12			39-45
or 21-455	Intermediate Real Analysis I	3 12			
21-325	Probability	9-12	Sophomore '	Year	
or 15-259	Probability and Computing	3 12	Fall		Unit
or 36-218	Probability Theory for Computer Scientists		21-325	Probability	9-12
38-330	ENGAGE in Wellness: Looking Outward	1	or 15-259	•	
XX-XXX	Technical Breadth Requirement	9	or 36-218	Probability Theory for Computer Scientists	
	Nontechnical Elective	9	21-373	Algebraic Structures	g
XX-XXX		9	XX-XXX	Technical Breadth Requirement	9
XX-XXX	Free Elective		XX-XXX	Nontechnical Elective	ç
		46-52	XX-XXX	Free Elective	ç
Spring		Units		Tree Elective	45-48
21-341	Linear Algebra	9			43-40
21-356	Principles of Real Analysis II	9-10	Spring		Units
or 21-456	Intermediate Real Analysis II		21-261	Introduction to Ordinary Differential Equations	10
21-xxx	Mathematical Sciences Elective	9	21-355	Principles of Real Analysis I	9-12
XX-XXX	Science and Society Course	6	or 21-455	Intermediate Real Analysis I	
XX-XXX	Cultural/Global Understanding Elective	9	38-230	ENGAGE in Wellness: Looking Inward	1
		42-43	XX-XXX	Technical Breadth Requirement	ç
		72-73	xx-xxx	Nontechnical Elective	g
Senior Year					38-41
Fall		Units			
21-xxx	Mathematical Sciences Elective	9	Junior Year		
21-xxx	Mathematical Sciences Elective	9	Fall		Units
38-110	ENGAGE in Service 1	1	21-356	Principles of Real Analysis II	9-10
38-220	ENGAGE in the Arts ¹	2	or 21-456	Intermediate Real Analysis II	3 10
		1	21-xxx	Mathematical Sciences Elective	Ç
38-430	ENGAGE in Wellness: Looking Forward Free Elective	9	38-330	ENGAGE in Wellness: Looking Outward	1
XX-XXX			XX-XXX	Cultural/Global Understanding Course	9
XX-XXX	Free Elective	9	XX-XXX	Free Elective	9
		40	<u> </u>	Tree Elective	37-38
Spring		Units			
21-xxx	Mathematical Sciences Elective	9	Spring		Unit
21-xxx	Mathematical Sciences Elective	9	21-341	Linear Algebra	9
VV VVV	Technical Breadth Requirement	9	21-xxx	Mathematical Sciences Elective	ç
XX-XXX	Free Elective	9	XX-XXX	Science and Society Course	(
	Tiee Liective			Technical Breadth Requirement	(
XX-XXX XX-XXX	Free Elective	9	XX-XXX	reclinical breadth Requirement	3
XX-XXX			xx-xxx xx-xxx	Nontechnical Elective	
XX-XXX		9 45		•	42
XX-XXX				•	g
XX-XXX				•	g
XX-XXX			xx-xxx	•	g

	·	
XX-XXX	Free Elective	9
XX-XXX	Free Elective	9
XX-XXX	Technical Breadth Requirement	9
21-xxx	Mathematical Sciences Elective	9
21-xxx	Mathematical Sciences Elective	9
Spring		Units
		49
XX-XXX	Free Elective	9
XX-XXX	Free Elective	9
XX-XXX	Free Elective	9
38-430	ENGAGE in Wellness: Looking Forward	1
38-220	ENGAGE in the Arts ¹	2
38-110	ENGAGE in Service ¹	1
21-xxx	Mathematical Sciences Elective	9

Minimum number of units required for degree:

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

An operations research professional employs quantitative and computational skills toward enhancing the function of an organization or process. Students choosing this concentration will develop problemsolving 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 College. By default, students must fulfill all 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 the Director of Undergraduate Studies.

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 for Computer Scientists	
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 15-259	Probability and Computing	
or 36-218	Probability Theory for Computer Scientists	
36-226	Introduction to Statistical Inference	9

36-410	Introduction to Probability Modeling	9
36-402	Advanced Methods for Data Analysis	9
36-401	Modern Regression	9

45-48

Economics, Business, and Computer Science Courses (required)

Courses		Units
15-110	Principles of Computing	10
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)

360

Forty-five units of (required) depth electives, to be chosen from the list below. At least one should be a math course (21-xxx). The courses 21-355 and 21-455 are particularly recommended for a student planning to pursue graduate work. Exceptions to the elective requirements for each concentration of the B.S. degree in Mathematical Sciences require prior approval from the student's academic advisor.

Courses		Units
10-301	Introduction to Machine Learning	12
or 10-315	Introduction to Machine Learning (SCS Majors)	
10-605	Machine Learning with Large Datasets	12
15-122	Principles of Imperative Computation	12
15-150	Principles of Functional Programming	12
15-210	Parallel and Sequential Data Structures and Algorithms	12
21-270	Introduction to Mathematical Finance	9
21-301	Combinatorics	9
21-321	Interactive Theorem Proving	9
21-341	Linear Algebra	9
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	
21-366	Topics in Applied Mathematics	9
21-370	Discrete Time Finance	9
21-373	Algebraic Structures	9
21-377	Monte Carlo Simulation for Finance	9
21-378	Mathematics of Fixed Income Markets	9
21-387	Monte Carlo Methods and Applications	9
21-420	Continuous-Time Finance	9
21-484	Graph Theory	9
36-461	Special Topics: Statistical Methods in Epidemiology	9
36-462	Special Topics: Statistical Machine Learning	9
36-463	Special Topics: Multilevel and Hierarchical Models	9
36-464	Special Topics: Psychometrics: A Statistical Modeling Approach	9
70-371	Operations Management	9
70-460	Mathematical Models for Consulting	9
70-467	Machine Learning for Business Analytics	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 requirements from the MCS general education core.

360

Suggested Schedule

21-120 Differential and Integral Calculus 10	Freshman Ye	ear	
21-241	Fall		Units
or 21-242 Matrix Theory 38-101 EUREKAI: Discovery and Its Impact 6 76-101 Interpretation and Argument 9 99-101 Core@CMU 3 xx-xxxx Technical Breadth Requirement 9 Spring Interpretation and Approximation 10-12 15-110 Principles of Computing 10-12 or 15-112 Fundamentals of Programming and Computer Science 12-127 21-127 Concepts of Mathematics 12 or 21-128 Mathematical Concepts and Proofs 10-12 21-122 Integration and Approximation 10 xx-xxx Technical Breadth Requirement 9 xx-xxx Nontechnical Elective 9 Sophomore Year Fall Units 21-201 Undergraduate Colloquium 1 21-228 Discrete Mathematics 9-12 or 15-251 Great Ideas in Theoretical Computer Scientics 9-12 or 21-266 Vector Calculus for Computer Scientists 10-12 xx-xxx Technical Breadth Requirement	21-120	Differential and Integral Calculus	10
38-101 EUREKA!: Discovery and Its Impact 76-101 Interpretation and Argument 99-101 Core@CMU xx-xxx Technical Breadth Requirement 99-101 Core@CMU xx-xxx Technical Breadth Requirement 99-101 Principles of Computing 10-12	21-241	Matrices and Linear Transformations	11
76-101 Interpretation and Argument 99-101 Core@CMU 33 X-xxx Technical Breadth Requirement 99-101 Core@CMU 33 Spring 15-110 Principles of Computing 10-12		•	
99-101 Core@CMU 3 xx-xxxx Technical Breadth Requirement 3 Spring Principles of Computing or 15-112 Units 15-110 15-110 Principles of Computing or 15-112 Fundamentals of Programming and Computer Science 21-127 Concepts of Mathematics 12 21-128 Mathematical Concepts and Proofs 12 21-122 Integration and Approximation 10 xx-xxxx Technical Breadth Requirement 9 xx-xxxx Nontechnical Elective 9 Sophomore Year Fall 21-201 Undergraduate Colloquium 1 21-228 Discrete Mathematics 9-12 or 15-251 Great Ideas in Theoretical Computer Science 10-12 1-29 Calculus in Three Dimensions 10-12 or 21-266 Vector Calculus for Computer Scientists 9-12 or 21-269 Vector Analysis 9-10 73-102 Principles of Microeconomics 9 xx-xxxx Technical Breadth Requirement 9 xx-xxxx T			
Spring Units		-	
Spring 15-110 Principles of Computing 10-12 On 15-112 Fundamentals of Programming and Computer Science 21-127 Concepts of Mathematics 12 Integration and Approximation 10 XX-XXX Technical Breadth Requirement 9 So-52 Sophomore Year Fall Undergraduate Colloquium 1 1 21-228 Discrete Mathematics 9-12 Or 15-251 Great Ideas in Theoretical Computer Science 21-279 Calculus in Three Dimensions 10-12 Or 21-266 Vector Calculus for Computer Scientists or 21-269 Vector Analysis 73-102 Principles of Microeconomics 9 Principles of Microeconomics 9 Open 21-261 Introduction to Ordinary Differential Equations or 33-231 Physical Analysis 12-129 Operations Research 1 9 Sa-230 ENGAGE in Wellness: Looking Inward 1 1 Sa-230 Probability and Computing 9 Or 36-218 Probability 1 Probability 9-12 Or 15-259 Probability 1 Proposality 1 Proposality 9-12 Or 15-259 Probability 1 Proposality 9-12 Or 15-259 Probability 1 Proposality 9-12 Or 15-259 Probability 1 Proposality 1			
Spring 15-110 Principles of Computing 10-12 or 15-112 Fundamentals of Programming and Computer Science 21-127 Concepts of Mathematics 12 or 21-128 Mathematical Concepts and Proofs 21-122 Integration and Approximation 10 xx-xxxx Technical Breadth Requirement 9 xx-xxx Nontechnical Elective 9 Sophomore Year Fall Units 21-201 Undergraduate Colloquium 1 21-228 Discrete Mathematics 9-12 or 15-251 Great Ideas in Theoretical Computer Science 21-259 Calculus in Three Dimensions 10-12 or 21-268 Multidimensional Calculus or 21-268 Multidimensional Calculus or 21-269 Vector Analysis 73-102 Principles of Microeconomics 9 xx-xxx Technical Breadth Requirement 9 38-43 Spring 21-260 Differential Equations 0 07 21-261 Introduction to Ordinary Differential Equations 0 07 21-261 Introduction to Accounting 9 38-230 ENGAGE in Wellness: Looking Inward 1 10-120 Introduction to Accounting 9 xx-xxx Technical Breadth Requirement 9 yx-xxxx Depth Elective 9 yrinciples of Macroeconomics 99 yrinciples of Macroeconomics	XX-XXX	Technical Breadth Requirement	
15-110 principles of Computing or 15-112 Fundamentals of Programming and Computer Science 21-127 Concepts of Mathematics or 21-128 Mathematical Concepts and Proofs 21-122 Integration and Approximation 10 xx-xxx Technical Breadth Requirement 9 xx-xxx Nontechnical Elective 9 Sophomore Year Fall Units 21-201 Undergraduate Colloquium 1 21-228 Discrete Mathematics 9-12 or 15-251 Great Ideas in Theoretical Computer Science 21-259 Calculus in Three Dimensions 0 10-12 or 21-266 Vector Calculus for Computer Scientists 0 21-268 Multidimensional Calculus 0 21-269 Vector Analysis 73-102 Principles of Microeconomics 9 xx-xxx Technical Breadth Requirement 9 21-260 Differential Equations 0 21-261 Introduction to Ordinary Differential Equations 0 33-231 Physical Analysis 21-292 Operations Research 1 9 9 10-12 Operations Research 1 9 1 New Xx-xxx Technical Breadth Requirement 9			48
or 15-112 Fundamentals of Programming and Computer Science 21-127 Concepts of Mathematics 07 21-128 Mathematical Concepts and Proofs 21-122 Integration and Approximation 10 xx-xxx Technical Breadth Requirement xx-xxx Nontechnical Elective 9 50-52 Sophomore Year Fall Uniter 21-201 Undergraduate Colloquium 11 21-201 Undergraduate Colloquium 11 21-201 Undergraduate Colloquium 11 21-225 Calculus in Three Dimensions 07 15-251 Great Ideas in Theoretical Computer Science 21-259 Calculus in Three Dimensions 07 21-260 Vector Calculus for Computer Scientists 07 21-269 Vector Analysis 73-102 Principles of Microeconomics 9 xx-xxx Technical Breadth Requirement 9 21-260 Differential Equations 07 21-261 Introduction to Ordinary Differential Equations 07 21-261 Introduction to Ordinary Differential Equations 07 21-27 09 Coperations Research 9 38-230 ENGAGE in Wellness: Looking Inward 10-122 Introduction to Accounting 10 11 12 13-103 Physical Analysis 10-122 Introduction to Accounting 10 11 12 13-104 Unite 21-325 Probability Medeling 13-105 Principles of Macroeconomics 13-103 Principles of Macroeconomics 13-213 Probability Theory for Computer Scientists 13-103 Principles of Macroeconomics 13-230 ENGAGE in Wellness: Looking Outward 14-43 Spring 15-250 Introduction to Statistical Inference 16-410 Introduction to Statistical Inference 17-20 Intermediate Microeconomics 19-12-20 Intermediate Microeconomics 19-12-20 Intermediate Microeconomics 19-12-20 Introduction to Statistical Inference 19-12-32-30 Intermediate Microeconomics 19-12-32-32-32-32-32-32-32-32	Spring		Units
21-127 Concepts of Mathematics or 21-128 Mathematical Concepts and Proofs 21-122 Integration and Approximation 10 xx-xxx Technical Breadth Requirement 9 50-52 Sophomore Year Fall 21-201 Undergraduate Colloquium 11 21-228 Discrete Mathematics or 15-251 Great Ideas in Theoretical Computer Science 21-259 Calculus in Three Dimensions or 21-266 Vector Calculus for Computer Scientists or 21-268 Multidimensional Calculus or 21-2709 Vector Analysis 73-102 Principles of Microeconomics xx-xxx Technical Breadth Requirement 9 21-260 Differential Equations or 31-231 Introduction to Ordinary Differential Equations or 33-231 Physical Analysis 21-292 Operations Research I 93-230 ENGAGE in Wellness: Looking Inward 70-122 Introduction to Accounting xx-xxxx Technical Breadth Requirement 99 xx-xxxx Technical Elective 90 yend in the Melhods 12 1-325 Probability or 15-259 Probability Theory for Computer Scientists 73-103 Principles of Macroeconomics 91 21-369 Numerical Methods 12 21-325 Probability Theory for Computer Scientists 73-103 Principles of Macroeconomics xx-xxxx Depth Elective 99 38-330 ENGAGE in Wellness: Looking Outward 10 11 11 11 11 11 11 11 11 11 11 11 11	15-110	Principles of Computing	10-12
or 21-128 Mathematical Concepts and Proofs 21-122 Integration and Approximation 10	or 15-112	Fundamentals of Programming and Computer Science	
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Fall		Units
21-393	Operations Research II	9
36-401	Modern Regression	9
XX-XXX	Depth Elective	9
38-110	ENGAGE in Service ¹	1
38-220	ENGAGE in the Arts ¹	2
38-430	ENGAGE in Wellness: Looking Forward	1
XX-XXX	Nontechnical Elective	9
XX-XXX	Free Elective	9
	·	49
		49
Spring		Units
Spring 36-402	Advanced Methods for Data Analysis	
	Advanced Methods for Data Analysis Depth Elective	Units
36-402	,	Units 9
36-402 xx-xxx	Depth Elective	Units 9
36-402 xx-xxx xx-xxx	Depth Elective Depth Elective	Units 9 9

Minimum number of units required for degree:

B.S. in Mathematical Sciences (Statistics)

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 courses 15-259 Probability and Computing and 36-226 Introduction to Statistical Inference taken in the junior year serve as the basis for all further statistics courses. The course 21-325 is a more mathematical alternative to 15-259.

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. By default, students must fulfill all 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 the Director of Undergraduate Studies. 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 for Computer Scientists	
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

Statistics Courses (required)

Courses		Units
21-325	Probability	9-12
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 and Computer Science Courses (required)

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

Depth Electives (required)

Forty-five units of (required) depth electives, including at least nine units in statistics, to be chosen from the list below. The courses 21-355 and 21-455 are particularly recommended for a student planning to pursue graduate work. Exceptions to the elective requirements for each concentration of the B.S. degree in Mathematical Sciences require prior approval from the student's academic advisor.

Courses		Units
10-301	Introduction to Machine Learning	12
or 10-315	Introduction to Machine Learning (SCS Majors)	
10-605	Machine Learning with Large Datasets	12
15-150	Principles of Functional Programming	12
15-210	Parallel and Sequential Data Structures and Algorithms	12
21-270	Introduction to Mathematical Finance	9
21-321	Interactive Theorem Proving	9
21-341	Linear Algebra	9
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	
21-366	Topics in Applied Mathematics	9
21-370	Discrete Time Finance	9
21-373	Algebraic Structures	9
21-377	Monte Carlo Simulation for Finance	9
21-378	Mathematics of Fixed Income Markets	9
21-387	Monte Carlo Methods and Applications	9
21-420	Continuous-Time Finance	9
21-484	Graph Theory	9
36-461	Special Topics: Statistical Methods in Epidemiology	9
36-462	Special Topics: Statistical Machine Learning	9
36-463	Special Topics: Multilevel and Hierarchical Models	9
36-464	Special Topics: Psychometrics: A Statistical Modeling Approach	9

MCS General Education (required)

MCS humanities, social sciences, and science core (114 units) Note that 73-102 satisfies a requirement from the MCS core.

Suggested Schedule

Freshman Year

Fall		Units
21-120	Differential and Integral Calculus	10
21-241	Matrices and Linear Transformations	11
or 21-242	Matrix Theory	

38-101	EUREKA!: Discovery and Its Impact	6
76-101	Interpretation and Argument	9
99-101	Core@CMU	3
XX-XXX	Technical Breadth Requirement	9
		48
Spring 15-112	Fundamentals of Programming and Computer Science	Units 12
21-127	Concepts of Mathematics	12
or 21-128	Mathematical Concepts and Proofs	
21-122	Integration and Approximation	10
XX-XXX XX-XXX	Technical Breadth Requirement Technical Breadth Requirement	9
AA AAA	reclinical breader requirement	52
Sophomore `	Year	
Fall	Hadamardaaba Callamiina	Units
21-201 21-228	Undergraduate Colloquium Discrete Mathematics	9-12
or 15-251	Great Ideas in Theoretical Computer Science	9-12
21-259	Calculus in Three Dimensions	10-12
or 21-266	Vector Calculus for Computer Scientists	
or 21-268	Multidimensional Calculus	
or 21-269	Vector Analysis	
73-102	Principles of Microeconomics	9
xx-xxx	Technical Breadth Requirements	9
XX-XXX	Nontechnical Elective	9
		47-52
Spring		Units
15-122	Principles of Imperative Computation	12
21-260	Differential Equations	9-10
or 21-261 or 33-231	Introduction to Ordinary Differential Equations	
21-292	Physical Analysis Operations Research I	9
38-230	ENGAGE in Wellness: Looking Inward	1
xx-xxx	Nontechnical Elective	9
XX-XXX	Free Elective	9
		49-50
Junior Year Fall		Units
21-369	Numerical Methods	12
21-325	Probability	9-12
or 15-259	Probability and Computing	
or 36-218	Probability Theory for Computer Scientists	
XX-XXX	Depth Elective	9
XX-XXX	Depth Elective	9
38-330	ENGAGE in Wellness: Looking Outward	1
XX-XXX	Nontechnical Elective	9
		49-52
Spring		Units
36-226	Introduction to Statistical Inference	9
36-410	Introduction to Probability Modeling	9
XX-XXX	Depth Elective	9
XX-XXX	Science and Society Course Cultural/Global Understanding Course	6
XX-XXX	Cultural/Global Officerstanding Course	42
Senior Year		
Fall		Units
21-393	Operations Research II	9
	Modern Pogression	9
36-401 xx-xxx	Modern Regression Depth Elective	9

ENGAGE in Service ¹

ENGAGE in the Arts ¹

1

38-110

38-220

38-430	ENGAGE in Wellness: Looking Forward	1
XX-XXX	Nontechical Elective	9
		40
Spring		Units
36-402	Advanced Methods for Data Analysis	9
XX-XXX	Depth Elective	9
XX-XXX	Depth Elective	9
XX-XXX	Free Elective	9
XX-XXX	Free Elective	9
		45

Minimum number of units required for degree:

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

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 firm 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. By default, students must fulfill all 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 the Director of Undergraduate Studies.

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. Students who plan to pursue graduate study in mathematical logic are strongly advised to take 21-300 Basic Logic.

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
21-241	Matrices and Linear Transformations	11
or 21-242	Matrix Theory	
21-300	Basic Logic	9
or 15-317	Constructive Logic	
21-228	Discrete Mathematics	9-12
or 15-251	Great Ideas in Theoretical Computer Science	
21-301	Combinatorics	9
21-341	Linear Algebra	9
21-355	Principles of Real Analysis I	9-12
or 21-455	Intermediate Real Analysis I	
21-373	Algebraic Structures	9

134-140

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
15-451	Algorithm Design and Analysis	12
15-453	Formal Languages, Automata, and Computability	9

Students pursuing this concentration who minor in Computer Science must take at least 18 units of 15-300 level (or above) courses to avoid excessive double-counting.

Mathematical Sciences Electives (required)

Sixty-three units of mathematical sciences electives, to be chosen from List 1 and 2 below, including at least twenty-seven units chosen from List 1. Exceptions to the elective requirements for each concentration of the B.S. degree in Mathematical Sciences require prior approval from the student's academic advisor.

List 1 (Discrete Mathematics and Logic Electives)

360

Courses		Units
15-259	Probability and Computing	12
21-321	Interactive Theorem Proving	9
21-322	Topics in Formal Mathematics	9
21-325	Probability	9
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
80-411	Proof Theory	9
80-413	Category Theory	9

List 2 (General Mathematics Electives)

LISC 2 (OCTICI	ar Mathematics Electives)	
Courses 21-259 or 21-266 or 21-268 or 21-269	Calculus in Three Dimensions Vector Calculus for Computer Scientists Multidimensional Calculus Vector Analysis	Units 10-12
21-260 or 21-261 or 33-231	Differential Equations Introduction to Ordinary Differential Equations Physical Analysis	9-10
21-270	Introduction to Mathematical Finance	9
21-292	Operations Research I	9
21-356 or 21-456	Principles of Real Analysis II Intermediate Real Analysis II	9-10
21-366	Topics in Applied Mathematics	9
21-369	Numerical Methods	12
21-370	Discrete Time Finance	9
21-371	Functions of a Complex Variable	9
21-387	Monte Carlo Methods and Applications	9
21-393	Operations Research II	9
21-420	Continuous-Time Finance	9
21-470	Selected Topics in Analysis	9
21-476	Introduction to Dynamical Systems	9
21-410	Research Topics in Mathematical Sciences	9
21-xxx	Any graduate course in mathematics at the 600 and 700 level not included in List 1	9-12

MCS General Education (required)

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

Suggested Schedule

Freshman Year

Fall		Units
15-112	Fundamentals of Programming and Computer Science	12
21-120	Differential and Integral Calculus	10
38-101	EUREKA!: Discovery and Its Impact	6
76-101	Interpretation and Argument	9
99-101	Core@CMU	3

XX-XXX	Life/Physical Sciences Course	9
		49
Spring		Units
15-122	Principles of Imperative Computation	12
21-122	Integration and Approximation	10
21-127	Concepts of Mathematics	12
or 21-128	Mathematical Concepts and Proofs	
21-241	Matrices and Linear Transformations	11
or 21-242	Matrix Theory	
xx-xxx	Technical Breadth Requirement	9
		54
Sophomore `	Year	
Fall		Units
15-150	Principles of Functional Programming	12
21-201	Undergraduate Colloquium	1
21-268	Multidimensional Calculus	11-12
or 21-269	Vector Analysis	
21-301	Combinatorics	9
21-373	Algebraic Structures	9
XX-XXX	Nontechnical Elective	9
		51-52
Spring		Units
15-210	Parallel and Sequential Data Structures and Algorithms	12
38-230	ENGAGE in Wellness: Looking Inward	1
XX-XXX	Discrete Math/Logic Elective	g
XX-XXX	Mathematics Elective	g
XX-XXX	Technical Breadth Requirement	9
XX-XXX	Nontechnical Elective	9
		l la ita
Junior Year Fall 15-xxx	Computer Science Elective	9
Fall 15-xxx 21-300	Basic Logic	9
Fall 15-xxx 21-300 or 15-317	Basic Logic Constructive Logic	9
Fall 15-xxx 21-300 or 15-317 21-355	Basic Logic Constructive Logic Principles of Real Analysis I	9
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I	9 9 9-12
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455 38-330	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward	Units 9 9 9-12
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455 38-330 xx-xxx	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward Technical Breadth Requirement	9-12 1 9-19
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455 38-330 xx-xxx	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward	9-12 1 9-2
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455 38-330 xx-xxx xx-xxx	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward Technical Breadth Requirement	9-12 1 9 9-46-49
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455 38-330 xx-xxx xx-xxx	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward Technical Breadth Requirement Nontechnical Elective	9-12 1 2 2 46-49 Units
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455 38-330 xx-xxx xx-xxx	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward Technical Breadth Requirement Nontechnical Elective Computer Science Elective	9-12 1 9 9 46-49 Units
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455 38-330 xx-xxx xx-xxx Spring 15-xxx 21-341	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward Technical Breadth Requirement Nontechnical Elective Computer Science Elective Linear Algebra	9-12 1 9 9 46-49 Units
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455 38-330 xx-xxx xx-xxx Spring 15-xxx 21-341 xx-xxx	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward Technical Breadth Requirement Nontechnical Elective Computer Science Elective Linear Algebra Science and Society Course	9-12 1 9 46-49 Units 9
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455 38-330 xx-xxx xx-xxx Spring 15-xxx 21-341 xx-xxx xx-xxx	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward Technical Breadth Requirement Nontechnical Elective Computer Science Elective Linear Algebra Science and Society Course Nontechnical Elective	9-12 1 2 46-49 Units
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward Technical Breadth Requirement Nontechnical Elective Computer Science Elective Linear Algebra Science and Society Course	9-12 1 2 2 46-49 Units 5
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455 38-330 xx-xxx xx-xxx Spring 15-xxx 21-341 xx-xxx xx-xxx xx-xxx Senior Year	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward Technical Breadth Requirement Nontechnical Elective Computer Science Elective Linear Algebra Science and Society Course Nontechnical Elective	9-12 1 1 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455 38-330 xx-xxx xx-xxx Spring 15-xxx 21-341 xx-xxx xx-xxx xx-xxx Senior Year Fall	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward Technical Breadth Requirement Nontechnical Elective Computer Science Elective Linear Algebra Science and Society Course Nontechnical Elective Cultural/Global Understanding Course	9-12 1 1 9 46-49 Units 9 42
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455 38-330 xx-xxx xx-xxx Spring 15-xxx 21-341 xx-xxx xx-xxx Senior Year Fall xx-xxx	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward Technical Breadth Requirement Nontechnical Elective Computer Science Elective Linear Algebra Science and Society Course Nontechnical Elective Cultural/Global Understanding Course Discrete Math/Logic Elective	9-12 1 1 9 9 46-49 Units 9 9 42
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455 38-330 xx-xxx xx-xxx Spring 15-xxx 21-341 xx-xxx xx-xxx Senior Year Fall xx-xxx xx-xxx	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward Technical Breadth Requirement Nontechnical Elective Computer Science Elective Linear Algebra Science and Society Course Nontechnical Elective Cultural/Global Understanding Course Discrete Math/Logic Elective Mathematics Elective	9-12 1 1 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455 38-330 xx-xxx xx-xxx Spring 15-xxx 21-341 xx-xxx xx-xxx Senior Year Fall xx-xxx xx-xxx xx-xxx xx-xxx	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward Technical Breadth Requirement Nontechnical Elective Computer Science Elective Linear Algebra Science and Society Course Nontechnical Elective Cultural/Global Understanding Course Discrete Math/Logic Elective Mathematics Elective Mathematics Elective	9-12 1 1 9 9 46-49 Units 9 9 42
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455 38-330 xx-xxx xx-xxx Spring 15-xxx 21-341 xx-xxx xx-xxx Senior Year Fall xx-xxx xx-xxx xx-xxx xx-xxx xx-xxx xx-xxx xx-xxx xx-xxx	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward Technical Breadth Requirement Nontechnical Elective Computer Science Elective Linear Algebra Science and Society Course Nontechnical Elective Cultural/Global Understanding Course Discrete Math/Logic Elective Mathematics Elective Mathematics Elective ENGAGE in Service 1	9-12 1 9-12 46-49 Units 9 9 42 Units
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455 38-330 xx-xxx xx-xxx Spring 15-xxx 21-341 xx-xxx xx-xxx Senior Year Fall xx-xxx	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward Technical Breadth Requirement Nontechnical Elective Computer Science Elective Linear Algebra Science and Society Course Nontechnical Elective Cultural/Global Understanding Course Discrete Math/Logic Elective Mathematics Elective ENGAGE in Service ENGAGE in the Arts Intermediate	9-12 1
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455 38-330 xx-xxx xx-xxx Spring 15-xxx 21-341 xx-xxx xx-xxx Senior Year Fall xx-xxx	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward Technical Breadth Requirement Nontechnical Elective Computer Science Elective Linear Algebra Science and Society Course Nontechnical Elective Cultural/Global Understanding Course Discrete Math/Logic Elective Mathematics Elective ENGAGE in Service ENGAGE in the Arts ENGAGE in Wellness: Looking Forward	9-12 1
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455 38-330 xx-xxx xx-xxx Spring 15-xxx 21-341 xx-xxx xx-xxx xx-xxx Senior Year	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward Technical Breadth Requirement Nontechnical Elective Computer Science Elective Linear Algebra Science and Society Course Nontechnical Elective Cultural/Global Understanding Course Discrete Math/Logic Elective Mathematics Elective ENGAGE in Service ENGAGE in the Arts Intermediate	9-12 1 1 9 9 9 46-49 Units 9 9 9 1 2 2 1 9 9
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455 38-330 xx-xxx xx-xxx Spring 15-xxx 21-341 xx-xxx xx-xxx Senior Year Fall xx-xxx	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward Technical Breadth Requirement Nontechnical Elective Computer Science Elective Linear Algebra Science and Society Course Nontechnical Elective Cultural/Global Understanding Course Discrete Math/Logic Elective Mathematics Elective ENGAGE in Service ENGAGE in the Arts ENGAGE in Wellness: Looking Forward	9-12 1 9-12 46-49 Units 9 9 42 Units 9 9 42 Units 9 9 9 44 44 Units
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455 38-330 xx-xxx xx-xxx Spring 15-xxx 21-341 xx-xxx xx-xxx Senior Year Fall xx-xxx	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward Technical Breadth Requirement Nontechnical Elective Computer Science Elective Linear Algebra Science and Society Course Nontechnical Elective Cultural/Global Understanding Course Discrete Math/Logic Elective Mathematics Elective Mathematics Elective ENGAGE in Service 1 ENGAGE in the Arts 1 ENGAGE in Wellness: Looking Forward Free Elective	9-12 1 1 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455 38-330 xx-xxx xx-xxx Spring 15-xxx 21-341 xx-xxx xx-xxx Senior Year Fall xx-xxx Spring xx-xxx	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward Technical Breadth Requirement Nontechnical Elective Computer Science Elective Linear Algebra Science and Society Course Nontechnical Elective Cultural/Global Understanding Course Discrete Math/Logic Elective Mathematics Elective ENGAGE in Service 1 ENGAGE in Wellness: Looking Forward Free Elective Discrete Math/Logic Elective	9-12 1 9-12 1 99 46-49 Units 99 42 Units 99 1 2 1 90 Units
Fall 15-xxx 21-300 or 15-317 21-355 or 21-455 38-330 xx-xxx xx-xxx Spring 15-xxx 21-341 xx-xxx xx-xxx Senior Year Fall xx-xxx	Basic Logic Constructive Logic Principles of Real Analysis I Intermediate Real Analysis I ENGAGE in Wellness: Looking Outward Technical Breadth Requirement Nontechnical Elective Computer Science Elective Linear Algebra Science and Society Course Nontechnical Elective Cultural/Global Understanding Course Discrete Math/Logic Elective Mathematics Elective Mathematics Elective ENGAGE in Service 1 ENGAGE in the Arts 1 ENGAGE in Wellness: Looking Forward Free Elective	9-12 1 9-12 1 99 46-49 Units 99 42 Units 99 42 Units

XX-XXX	Mathematics Elective	9
XX-XXX	Free Elective	9
		36
Minimum	number of units required for degree:	360

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

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. By default, students must fulfill all 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 the Director of Undergraduate Studies.

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 for Computer Scientists	
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 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

114-126

Depth Electives (required)

Students must take twenty-seven units of depth electives, to be chosen from the list below. Exceptions to the elective requirements for each concentration of the B.S. degree in Mathematical Sciences require prior approval from the student's academic advisor.

Courses		Units
10-301	Introduction to Machine Learning	12
or 10-315	Introduction to Machine Learning (SCS Majors)	
21-270	Introduction to Mathematical Finance	9
21-292	Operations Research I	9
21-344	Numerical Linear Algebra	9
21-380	Introduction to Mathematical Modeling	9
21-435	Applied Harmonic Analysis	9

49

9

Units

Computer Science Courses (required)

Courses		Units
15-122	Principles of Imperative Computation	12

Mathematics Electives (required)

Students must take 27 units either from the three remaining courses from the depth electives or from the list below:

Courses		Units
21-321	Interactive Theorem Proving	9
21-322	Topics in Formal Mathematics	9
21-341	Linear Algebra	9
21-356	Principles of Real Analysis II	9-10
or 21-456	Intermediate Real Analysis II	
21-366	Topics in Applied Mathematics	9
21-370	Discrete Time Finance	9
21-371	Functions of a Complex Variable	9
21-373	Algebraic Structures	9
21-377	Monte Carlo Simulation for Finance	9
21-378	Mathematics of Fixed Income Markets	9
21-387	Monte Carlo Methods and Applications	9
21-393	Operations Research II	9
21-420	Continuous-Time Finance	9
21-470	Selected Topics in Analysis	9
21-476	Introduction to Dynamical Systems	9
21-484	Graph Theory	9
21-620	Real Analysis	6
21-621	Introduction to Lebesgue Integration	6
21-630	Ordinary Differential Equations	12
21-632	Introduction to Differential Equations	12
21-640	Introduction to Functional Analysis	12
21-651	General Topology	12
21-660	Introduction to Numerical Analysis I	12
21-690	Methods of Optimization	12
21-720	Measure and Integration	12
21-721	Probability	12
21-723	Advanced Real Analysis	12
21-732	Partial Differential Equations I	12
21-832	Partial Differential Equations II	12

Students must take nine additional units of 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.

21-366 Topics in Applied Mathematics and 21-470 Selected Topics in Analysis have content that varies from year to year. These courses can be taken more than once (with permission).

Note that courses 21-600 and above carry graduate credit. 600-level courses are designed as transitional courses to graduate study.

A student preparing for graduate study should also consider undertaking independent work. The Department offers 21-410 Research Topics in Mathematical Sciences and 21-599 Undergraduate Reading and Research for this purpose.

Courses 21-700 and above can be used with the permission of both the advisor and the department.

MCS General Education (required)

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

Suggested Schedule

Freshman Year

Fall		Units
21-120	Differential and Integral Calculus	10
21-241	Matrices and Linear Transformations	11
or 21-242	Matrix Theory	
38-101	EUREKA!: Discovery and Its Impact	6
76-101	Interpretation and Argument	9

Spring

xx-xxx

Mathematics Elective

XX-XXX	Technical Breadth Requirement	9 45
Spring		Units
21-122 21-127	Integration and Approximation	10 12
or 21-128	Concepts of Mathematics Mathematical Concepts and Proofs	12
21-228	Discrete Mathematics	g
XX-XXX	Technical Breadth Requirement	9
XX-XXX	Nontechnical Elective	9
		49
Sophomore `	Year	
Fall		Units
15-112	Fundamentals of Programming and Computer Science	12
21-201	Undergraduate Colloquium	1
21-268	Multidimensional Calculus	11-12
or 21-269	Vector Analysis	
XX-XXX	Technical Breadth Requirement Nontechnical Elective	9
XX-XXX	Nontechnical Elective	9
		42-43
Spring		Units
15-122	Principles of Imperative Computation	12
21-261	Introduction to Ordinary Differential Equations	9-12
21-355 or 21-455	Principles of Real Analysis I Intermediate Real Analysis I	9-12
38-230	ENGAGE in Wellness: Looking Inward	1
XX-XXX	Technical Breadth Requirement	9
xx-xxx	Nontechnical Elective	9
Fall 21-325 or 15-259	Probability Probability and Computing	Units 9-12
or 36-218	Probability Theory for Computer Scientists	
21-356	Deinsieles of Deal Analysis II	0.10
or 21 456	Principles of Real Analysis II	9-10
or 21-456	Intermediate Real Analysis II	
or 21-456 38-330 xx-xxx		1
38-330	Intermediate Real Analysis II ENGAGE in Wellness: Looking Outward	1
38-330 xx-xxx	Intermediate Real Analysis II ENGAGE in Wellness: Looking Outward Nontechnical Elective	9-10 1 9 9
38-330 xx-xxx	Intermediate Real Analysis II ENGAGE in Wellness: Looking Outward Nontechnical Elective	1 9 9 37-41
38-330 xx-xxx xx-xxx	Intermediate Real Analysis II ENGAGE in Wellness: Looking Outward Nontechnical Elective	1 9 9 37-41 Units
38-330 xx-xxx xx-xxx	Intermediate Real Analysis II ENGAGE in Wellness: Looking Outward Nontechnical Elective Free Elective	1 9 9 37-41 Units
38-330 xx-xxx xx-xxx Spring 21-369	Intermediate Real Analysis II ENGAGE in Wellness: Looking Outward Nontechnical Elective Free Elective Numerical Methods Mathematics Elective Depth Elective	1 9 9 37-41 Units 12
38-330 xx-xxx xx-xxx Spring 21-369 xx-xxx xx-xxx xx-xxx	Intermediate Real Analysis II ENGAGE in Wellness: Looking Outward Nontechnical Elective Free Elective Numerical Methods Mathematics Elective Depth Elective Science and Society Course	1 9 9 37-41 Units 12 9
38-330 xx-xxx xx-xxx Spring 21-369 xx-xxx xx-xxx xx-xxx xx-xxx xx-xxx	Intermediate Real Analysis II ENGAGE in Wellness: Looking Outward Nontechnical Elective Free Elective Numerical Methods Mathematics Elective Depth Elective Science and Society Course Cultural/Global Understanding Elective	1 9 9 37-41 Units 12 9
38-330 xx-xxx xx-xxx Spring 21-369 xx-xxx xx-xxx xx-xxx	Intermediate Real Analysis II ENGAGE in Wellness: Looking Outward Nontechnical Elective Free Elective Numerical Methods Mathematics Elective Depth Elective Science and Society Course	1 9 9 37-41 Units 12 9 9
38-330 xx-xxx xx-xxx Spring 21-369 xx-xxx xx-xxx xx-xxx xx-xxx xx-xxx	Intermediate Real Analysis II ENGAGE in Wellness: Looking Outward Nontechnical Elective Free Elective Numerical Methods Mathematics Elective Depth Elective Science and Society Course Cultural/Global Understanding Elective	1 9 9 37-41 Units 12 9 9
38-330 xx-xxx xx-xxx Spring 21-369 xx-xxx xx-xxx xx-xxx xx-xxx xx-xxx xx-xxx	Intermediate Real Analysis II ENGAGE in Wellness: Looking Outward Nontechnical Elective Free Elective Numerical Methods Mathematics Elective Depth Elective Science and Society Course Cultural/Global Understanding Elective	1 9 9 37-41 Units 12 9 9 9
38-330 xx-xxx xx-xxx Spring 21-369 xx-xxx xx-xxx xx-xxx xx-xxx xx-xxx xx-xxx xx-xxx	Intermediate Real Analysis II ENGAGE in Wellness: Looking Outward Nontechnical Elective Free Elective Numerical Methods Mathematics Elective Depth Elective Science and Society Course Cultural/Global Understanding Elective	1 9 9 37-41 Units 12 9 9 9
38-330 xx-xxx xx-xxx Spring 21-369 xx-xxx xx-xxx xx-xxx xx-xxx xx-xxx xx-xxx xx-xxx xx-xxx	Intermediate Real Analysis II ENGAGE in Wellness: Looking Outward Nontechnical Elective Free Elective Numerical Methods Mathematics Elective Depth Elective Science and Society Course Cultural/Global Understanding Elective Free Elective	9 9 9 9 9 9 9 Units
38-330 xx-xxx xx-xxx Spring 21-369 xx-xxx xx-xxx xx-xxx xx-xxx xx-xxx xx-xxx xx-xxx xx-xxx	Intermediate Real Analysis II ENGAGE in Wellness: Looking Outward Nontechnical Elective Free Elective Numerical Methods Mathematics Elective Depth Elective Science and Society Course Cultural/Global Understanding Elective Free Elective Mathematics Elective Mathematics Elective Depth Elective	9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9
38-330 xx-xxx xx-xxx Spring 21-369 xx-xxx	Intermediate Real Analysis II ENGAGE in Wellness: Looking Outward Nontechnical Elective Free Elective Numerical Methods Mathematics Elective Depth Elective Science and Society Course Cultural/Global Understanding Elective Free Elective Mathematics Elective Mathematics Elective Depth Elective ENGAGE in Service 1	1 9 9 37-41 Units 12 9 9 48 Units 9
38-330 xx-xxx xx-xxx Spring 21-369 xx-xxx	Intermediate Real Analysis II ENGAGE in Wellness: Looking Outward Nontechnical Elective Free Elective Numerical Methods Mathematics Elective Depth Elective Science and Society Course Cultural/Global Understanding Elective Free Elective Mathematics Elective Mathematics Elective Mathematics Elective ENGAGE in Service ENGAGE in the Arts Intermediate Real Analysis II ENGAGE in Wellness: Looking Outward Numerical Methods Mathematics Elective ENGAGE in Service ENGAGE in the Arts Intermediate Real Analysis II ENGAGE Intermediate Real Analysis II E	1 9 9 37-41 Units 12 9 9 48 Units 9
38-330 xx-xxx xx-xxx Spring 21-369 xx-xxx	Intermediate Real Analysis II ENGAGE in Wellness: Looking Outward Nontechnical Elective Free Elective Numerical Methods Mathematics Elective Depth Elective Science and Society Course Cultural/Global Understanding Elective Free Elective Mathematics Elective Mathematics Elective Mathematics Elective ENGAGE in Service ENGAGE in the Arts ENGAGE in Wellness: Looking Forward	1 9 9 37-41 Units 12 9 9 48 Units 9 9
38-330 xx-xxx xx-xxx Spring 21-369 xx-xxx	Intermediate Real Analysis II ENGAGE in Wellness: Looking Outward Nontechnical Elective Free Elective Numerical Methods Mathematics Elective Depth Elective Science and Society Course Cultural/Global Understanding Elective Free Elective Mathematics Elective Mathematics Elective Mathematics Elective ENGAGE in Service ENGAGE in the Arts Intermediate Real Analysis II ENGAGE in Wellness: Looking Outward Numerical Methods Mathematics Elective ENGAGE in Service ENGAGE in the Arts Intermediate Real Analysis II ENGAGE Intermediate Real Analysis II E	37-41 Units 12 9 9 48 Units

xx-xxx Depth Elective 9 xx-xxx Free Elective 9 xx-xxx Free Elective 9 xx-xxx Free Elective 9 45 45	Minimum	number of units required for degree:	360
xx-xxx Free Elective 9 xx-xxx Free Elective 9			45
xx-xxx Free Elective 9	XX-XXX	Free Elective	9
_ ' _, .	XX-XXX	Free Elective	9
xx-xxx Depth Elective 9	XX-XXX	Free Elective	9
	XX-XXX	Depth Elective	9

B.A. in Mathematical Sciences

Mathematical Sciences Courses (required)

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 for Computer Scientists	
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 15-259	Probability and Computing	
or 36-218	Probability Theory for Computer Scientists	

Forty-five units of Mathematical Sciences electives (at the 21-300 level or above: or 21-270 or 21-292).

Twenty-seven units of 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 (at the 36-300 level or above; and have at least 36-225 as a prerequisite) electives.

MCS General Education (required)

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

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. In order to avoid double-counting issues, students are encouraged to consult with their degree advisor 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

The Minor in Mathematical Sciences

The minor includes six courses. 21-127 Concepts of Mathematics is a prerequisite for 21-228 and recommended for 21-241 . The minimum preparation required for 21-355 Principles of Real Analysis I is 21-122 and 21-127 or equivalent courses. Please see below if you are a Computational Finance major.

21-127	Concepts of Mathematics	12
or 21-128	Mathematical Concepts and Proofs	
or 15-151	Mathematical Foundations for Computer Science	
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	
21-355	Principles of Real Analysis I	9-12
or 21-455	Intermediate Real Analysis I	
21-xxx	Mathematical Sciences Elective (300-level or higher)	9-12
21-xxx	Mathematical Sciences Elective (300-level or higher)	9-12

To avoid excessive double-counting, the two mathematical sciences electives may not also count toward any other major or minor requirement.

Computational Finance majors who declare a minor in Mathematical
Sciences should take the following six courses:

Required courses are:

21-127	Concepts of Mathematics	12
or 21-128	Mathematical Concepts and Proofs	
or 15-151	Mathematical Foundations for Computer Science	
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	
21-355	Principles of Real Analysis I	9
21-325	Probability	9-12
or 15-259	Probability and Computing	
or 36-218	Probability Theory for Computer Scientists	

Nine units of Mathematical Sciences Electives, to be chosen from the following list:

21-300	Basic Logic	9
21-301	Combinatorics	9
21-329	Set Theory	9
21-373	Algebraic Structures	9
21-484	Graph Theory	9

^{*}Students who take 21-325 (or 15-259 or 36-218) to fulfill their BSCF requirements should take an additional 21-3xx elective to avoid excessive double counting.

The Minor in Discrete Mathematics and Logic

This minor develops the fundamentals of discrete mathematics and logic necessary to understand the mathematical foundations of many computer related disciplines. Required courses are:

21-228	Discrete Mathematics ¹	9-12
or 15-251	Great Ideas in Theoretical Computer Science	
21-300	Basic Logic	9
or 15-317	Constructive Logic	
21-301	Combinatorics	9

¹21-127 Concepts of Mathematics is a prerequisite for 21-228.

Twenty-seven units of Mathematical Sciences Electives, to be chosen from the following two groups (at least nine units from each group).

Logic		
21-321	Interactive Theorem Proving	9
21-329	Set Theory	9
21-400	Intermediate Logic	9
21-602	Introduction to Set Theory I	12
21-603	Model Theory I	12
80-305	Game Theory	9
80-315	Logics for Knowledge and Belief	9
80-411	Proof Theory	9
80-413	Category Theory	9

Algebra and Discrete Mathematics

21-341	Linear Algebra		
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Students must register for this course no later than their penultimate semester. But, work for this course can be begun in any semester prior to registration.

21-373	Algebraic Structures	9
21-374	Field Theory	9
21-441	Number Theory	9
21-484	Graph Theory	9
21-610	Algebra I	12
21-701	Discrete Mathematics	12

The Honors Degree Program

This demanding program qualifies the student for an additional degree, the Master of Science in Mathematical Sciences. Admission to the Honors Degree Program is selective and interested students should apply for admission during their junior year. In the application process, the Department will hold to the same high standards which apply to admission to any graduate program. Applicants are not absolutely required to have taken the Mathematical Studies courses and may be admitted on the basis of exceptionally strong performance in non-honors mathematics courses or of accomplishments in research. Applicants are expected to have completed the Mathematical Studies sequences in algebra and analysis or 21-355/21-356 and 21-373/21-341 prior to application. 21-455/21-456 may be taken in place of 21-355/21-356.

In order to complete the Honors Degree Program, students must complete five mathematics graduate courses with grades of B or better and write an honors thesis. At the time of admission, students will declare a timetable on which they plan to take the graduate courses, do the research required for the thesis, and write up their work: this timetable can naturally be adjusted as required. At most, one of these five graduate courses may be applied towards the student's bachelor degree program.

At least three graduate courses must come from the list of Basic Examinations courses (https://www.cmu.edu/math/grad/phd/requirements.html).

Currently these are listed as:

- · 21-651 General Topology
- 21-640 Introduction to Functional Analysis
- 21-720 Measure and Integration
- 21-721 Probability
- 21-701 Discrete Mathematics
- 21-737 Probabilistic Combinatorics
- 21-602 Introduction to Set Theory I
- 21-610 Algebra I
- 21-603 Model Theory I
- 21-632 Introduction to Differential Equations

By special permission of the department, one graduate course with sufficient mathematical content offered in another department may be counted. The honors thesis may either be research-based or expository: expository theses must be at a high mathematical level, at least that of a second-year graduate course. Students should plan on finding a thesis advisor by the end of their junior year. Students are required to take 21-901 Master's Degree Research during their senior year, subject to the following conditions:

- Students must pass a minimum of 15 units of 21-901 to earn the M.S. in Mathematical Sciences.
- Students who have not defended their thesis by the Add Course Deadline during each of their last two semesters must register for a minimum of three units of 21-901 for that semester.
- 3. Students may not overload more than 66 units while taking 21-901.

The Master of Science in Mathematical Sciences may be earned together with a bachelor of science from another department.

Faculty

NOHA ABDELGHANY, Assistant Teaching Professor - Ph.D., Western Michigan University; Carnegie Mellon, 2022-

THERESA ANDERSON, Associate Professor – Ph.D., Brown University; Carnegie Mellon, 2022–

JEREMY AVIGAD, Professor - Ph.D., University of California, Berkeley; Carnegie Mellon, 1996-

NICHOLAS BOFFI , Assistant Professor – Ph.D., Harvard University ; Carnegie Mellon, 2024–

THOMAS BOHMAN, Professor - Ph.D., Rutgers University; Carnegie Mellon, 1998-

BORIS BUKH, Professor - Ph.D., Princeton University; Carnegie Mellon, 2012-

CLINTON CONLEY, Associate Professor - Ph.D., University of California Los Angeles; Carnegie Mellon, 2014-

JAMES CUMMINGS, Professor - Ph.D., Cambridge University; Carnegie Mellon. 1996-

HASAN DEMIRKOPARAN, Teaching Professor of Mathematics - Ph.D., Michigan State University; Carnegie Mellon, 2005-

LAYAN EL HAJJ, Associate Teaching Professor - Ph.D., McGill University; Carnegie Mellon. 2023-

CHRISTOPHER EUR, Assistant Professor - Ph.D., University of California, Berkeley; Carnegie Mellon, 2024-

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IRENE FONSECA, Kavčić-Moura University Professor of Mathematics - Ph.D., University of Minnesota; Carnegie Mellon, 1987-

FLORIAN FRICK, Associate Professor - Ph.D., Technical University of Berlin; Carnegie Mellon, 2018-

ALAN FRIEZE, Orion Hoch, S 1952, University Professor of Mathematical Sciences – Ph.D., University of London; Carnegie Mellon, 1987–

IRINA GHEORGHICIUC, Associate Teaching Professor - Ph.D., University of Pennsylvania; Carnegie Mellon, 2007-

RAMI GROSSBERG, Professor – Ph.D., Hebrew University of Jerusalem; Carnegie Mellon, 1988–

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WILLIAM HRUSA, Professor – Ph.D., Brown University; Carnegie Mellon,

GAUTAM IYER, Professor - Ph.D., University of Chicago; Carnegie Mellon, 2009-

GREGORY JOHNSON, Associate Teaching Professor - Ph.D., University of Maryland; Carnegie Mellon, 2009-

NIRAJ KHARE, Associate Teaching Professor - Ph.D., Ohio State University; Carnegie Mellon, 2014-

DAVID KINDERLEHRER, Alumni Professor of Mathematical Sciences - Ph.D., University of California at Berkeley; Carnegie Mellon, 1990-

DMITRY KRAMKOV, Mellon College of Science Professor of Mathematical Finance - Ph.D., Steklov Mathematical Institute; Carnegie Mellon, 2000-

MARTIN LARSSON, Professor - Ph.D., Cornell University; Carnegie Mellon, 2019.

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PO-SHEN LOH, Professor - Ph.D., Princeton University; Carnegie Mellon, 2009-

JOHN MACKEY, Teaching Professor - Ph.D., University of Hawaii; Carnegie Mellon. 2003-

ROBIN NEUMAYER, Assistant Professor - Ph.D., The University of Texas at Austin; Carnegie Mellon, 2021-

CLIVE NEWSTEAD, Assistant Teaching Professor - PhD, Carnegie Mellon University; Carnegie Mellon, 2018-

DAVID OFFNER, Associate Teaching Professor - Ph.D., Carnegie Mellon University; Carnegie Mellon, 2019-

WESLEY PEGDEN, Professor - Ph.D., Rutgers University; Carnegie Mellon, 2013-

AGOSTON PISZTORA, Associate Professor - Ph.D., ETH Zurich; Carnegie Mellon. 1996-

DYLAN QUINTANA, Assistant Teaching Professor - Ph.D., University of Chicago; Carnegie Mellon, 2023-

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MYKHAYLO SHKOLNIKOV, Professor - Ph.D., Stanford University; Carnegie Mellon. 2024-

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RICHARD STATMAN, Professor - Ph.D., Stanford University; Carnegie Mellon, 1984-

PRASAD TETALI, Alexander M. Knaster Professor & Department Head - Ph.D., New York University; Carnegie Mellon, 2021-

IAN TICE, Professor - Ph.D., New York University; Carnegie Mellon, 2012-

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NOEL WALKINGTON, Professor – Ph.D., University of Texas at Austin; Carnegie Mellon, 1989–

ANTHONY WESTON, Associate Teaching Professor – Ph.D., Kent State University; Carnegie Mellon, 2022–

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ZELEALEM YILMA, Associate Teaching Professor - Ph.D., Carnegie Mellon University; Carnegie Mellon, 2015-

MICHAEL YOUNG, Associate Professor & Mellon College of Science Associate Dean for Diversity, Equity and Inclusion – Ph.D., Carnegie Mellon University; Carnegie Mellon, 2021–

Emeriti Faculty

PETER ANDREWS, Professor Emeritus - Ph.D., Princeton University; Carnegie Mellon, 1963-

MANUEL BLUM, University Professor Emeritus - Ph.D., Massachusetts Institute of Technology; Carnegie Mellon, 1999-

DEBORAH BRANDON, Associate Teaching Professor Emerita - Ph.D., Carnegie Mellon University; Carnegie Mellon, 1991-

GÉRARD CORNUÉJOLS, IBM University Professor of Operations Research Emeritus – Ph.D., Cornell University; Carnegie Mellon, 1978–

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ROBERT SEKERKA, University Professor Emeritus - Ph.D., Harvard University; Carnegie Mellon, 1969-

STEVEN SHREVE, University Professor Emeritus - Ph.D., University of Illinois; Carnegie Mellon, 1980-

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RUSSELL WALKER, Teaching Professor Emeritus - D.A., Carnegie Mellon University; Carnegie Mellon, 1984-

WILLIAM WILLIAMS, Professor Emeritus - Ph.D., Brown University; Carnegie Mellon, 1966-