Department of Mathematical Sciences

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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, which is expected to be among the growth occupations over the next decade. 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 section of the catalog.

Special options within the Department

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, we offer 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.

Mathematical Studies

Following the 21-242/21-269 sequence, we offer 21-235 Mathematical Studies Analysis I/21-236 Mathematical Studies Analysis II and 21-237 Mathematical Studies Algebra I/21-237 Mathematical Studies Algebra I. These courses provide excellent preparation for graduate study, with many of the participants taking graduate courses as early as their Junior year. The typical enrollment of about 15 students allows for close contact with faculty. Admission to Mathematical Studies is by invitation, and interested students should apply during the Spring of their Freshman year.

Honors Degree Program

This demanding program qualifies the student for two degrees: The Bachelor of Science and the Master of Science in Mathematical Sciences. This program typically includes the Mathematical Studies option. For students who complete the Mathematical Studies sequence, the Master of Science degree in Mathematical Sciences may be earned together with a Bachelor of Science from another department.

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/servicesandoptions/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 Science and Humanities Scholars (http://coursecatalog.web.cmu.edu/servicesandoptions/intercollegeprograms/#scienceandhumanitiesscholarsprogram) program includes an option shared with the Statistics Department in the Humanities and Social Sciences College that leads to a BS in Mathematics and Statistics.
- The Bachelor of Science in Mathematics and Economics (http://coursecatalog.web.cmu.edu/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/servicesandoptions/intercollegeprograms/#bachelorofscienceincomputationalfinance). (http://coursecatalog.web.cmu.edu/servicesandoptions/intercollegeprograms/#bachelorofscienceincomputationalfinance)

Curricula

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 21-272 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.

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.

An H&SS Elective refers to a course in the Dietrich College of Humanities and Social Sciences requirements as described in the catalog section for the Mellon College of Science. 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 (http://coursecatalog.web.cmu.edu/melloncollegeofscience/#generaleducationrequirementstext) requirements.

Mathematical Sciences Concentration

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. The requirements for the Mathematics Degree 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	10
or 21-128	Mathematical Concepts and Proofs	
21-228	Discrete Mathematics	9
or 15-251	Great Ideas in Theoretical Computer Science	
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
36-225	Introduction to Probability Theory	9
or 21-325	Probability	
21-259	Calculus in Three Dimensions	9
or 21-268	Multidimensional Calculus	
or 21-269	Vector Analysis	
21-260	Differential Equations	9
or 21-261	Introduction to Ordinary Differential Equations	
or 33-231	Physical Analysis	
21-341	Linear Algebra	9
21-355	Principles of Real Analysis I	9
21-356	Principles of Real Analysis II	9
21-373	Algebraic Structures	9
		112

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

27 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 have at least 36-225 as a prerequisite) electives.

MCS General Education (required)

MCS or SHS 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:

Courses		Units
21-272	Introduction to Partial Differential Equations	9
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
21-467	Differential Geometry	9
21-470	Selected Topics in Analysis	9
21-476	Introduction to Dynamical Systems	9
21-484	Graph Theory	9
21-600	Mathematical Logic I	12
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 21-499 Undergraduate Research Topic and 21-599 Undergraduate Reading and Research for this purpose.

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

Suggested Schedule for students without AP credit

Freshman Year

Fall		Units
21-120	Differential and Integral Calculus	10
21-127	Concepts of Mathematics	10
or 21-128	Mathematical Concepts and Proofs	
38-101	First-year Seminar	6
76-101	Interpretation and Argument	9
99-101	Computing @ Carnegie Mellon	3
xx-xxx	Life/Physical Sciences Course	9
		47

Spring		Units
15-110	Principles of Computing	10
or 15-112	Fundamentals of Programming and Computer Science	
21-122	Integration and Approximation	10
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
xx-xxx	Physical/Life Sciences Course	9
xx-xxx	H&SS Elective	9
		48

Sophomore Year

Fall		Units
21-228	Discrete Mathematics	9
or 15-251	Great Ideas in Theoretical Computer Science	
21-268	Multidimensional Calculus	10
xx-xxx	STEM Course	9
xx-xxx	H&SS Elective	9
xx-xxx	Free Elective	9
		46

Spring		Units
21-261	Introduction to Ordinary Differential Equations	10
21-373	Algebraic Structures	9
xx-xxx	Mathematical Sci, Statistics, or Computer Sci Elective	9
xx-xxx	STEM Course	9
xx-xxx	H&SS Elective	9
		46

Junior Year

Fall		Units
21-355	Principles of Real Analysis I	9
36-225	Introduction to Probability Theory	9
or 21-325	Probability	
xx-xxx	Mathematical Sci, Statistics, or Computer Sci Elective	9
xx-xxx	H&SS Elective	9
xx-xxx	Free Elective	9
		45

Spring		Units
21-341	Linear Algebra	9
21-356	Principles of Real Analysis II	9
21-xxx	Mathematical Sciences Elective	9
xx-xxx	Cultural/Global Understanding Elective	9
xx-xxx	Free Elective	9
		45

Senior Year

Fall		Units
21-xxx	Mathematical Sciences Elective	9

21-xxx	Mathematical Sciences Elective	9
xx-xxx	Free Elective	9
xx-xxx	Free Elective	9
xx-xxx	Free Elective	9
		45

Spring		Units
21-xxx	Mathematical Sciences Elective	9
21-xxx	Mathematical Sciences Elective	9
xx-xxx	Mathematical Sci, Statistics, or Computer Sci Elective	9
xx-xxx	Free Elective	9
xx-xxx	Free Elective	9
		45

Minimum number of units required for degree: 360

Suggested Schedule for Students with AP Credit

Freshman Year

Fall		Units
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
21-127	Concepts of Mathematics	10
or 21-128	Mathematical Concepts and Proofs	
38-101	First-year Seminar	6
76-101	Interpretation and Argument	9
99-101	Computing @ Carnegie Mellon	3
xx-xxx	Life/Physical Sciences Course	9
		47

Spring		Units
15-110	Principles of Computing	10
or 15-112	Fundamentals of Programming and Computer Science	
21-228	Discrete Mathematics	9
or 15-251	Great Ideas in Theoretical Computer Science	
21-268	Multidimensional Calculus	10
or 21-269	Vector Analysis	
xx-xxx	H&SS Elective	9
		38

Sophomore Year

Fall		Units
36-225	Introduction to Probability Theory	9
or 21-325	Probability	
xx-xxx	Mathematical Sci, Statistics, or Computer Sci Elective	9
xx-xxx	H&SS Elective	9
xx-xxx	Free Elective	9
		36

Spring		Units
21-261	Introduction to Ordinary Differential Equations	10
21-355	Principles of Real Analysis I	9
xx-xxx	STEM Course	9
xx-xxx	H&SS Elective	9
		37

Junior Year

Fall		Units
21-356	Principles of Real Analysis II	9
21-xxx	Mathematical Sciences Elective	9
xx-xxx	Cultural/Global Understanding Course	9
xx-xxx	Free Elective	9
		36

Spring		Units
21-341	Linear Algebra	9
xx-xxx	Mathematical Sci, Statistics, or Computer Sci Elective	9
21-xxx	Mathematical Sciences Elective	9
xx-xxx	H&SS Elective	9
xx-xxx	Free Elective	9
		45

Senior Year

Fall		Units
21-xxx	Mathematical Sciences Elective	9
21-xxx	Mathematical Sciences Elective	9
xx-xxx	Free Elective	9
xx-xxx	Free Elective	9
xx-xxx	Free Elective	9
		45

Spring		Units
21-xxx	Mathematical Sciences Elective	9
21-xxx	Mathematical Sciences Elective	9
xx-xxx	Mathematical Sci, Statistics, or Computer Sci Elective	9
xx-xxx	Free Elective	9
xx-xxx	Free Elective	9
		45

Minimum number of units required for degree: 360

Operations Research and Statistics Concentration

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 program also includes a group project to be undertaken in the Senior year.

Students choosing this concentration may not pursue an additional major or minor in Statistics in the Humanities and Social Sciences College.

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	10
or 21-128	Mathematical Concepts and Proofs	
21-228	Discrete Mathematics	9
or 15-251	Great Ideas in Theoretical Computer Science	
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
21-259	Calculus in Three Dimensions	9
or 21-268	Multidimensional Calculus	
or 21-269	Vector Analysis	
21-260	Differential Equations	9
or 21-261	Introduction to Ordinary Differential Equations	
or 33-231	Physical Analysis	
21-292	Operations Research I	9
21-369	Numerical Methods	9
Starting Fall 2018, 21-369 will be 12 units with recitation.		
21-393	Operations Research II	9
		94

Statistics Courses (required)

Courses		Units
36-225	Introduction to Probability Theory	9
or 21-325	Probability	

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

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	
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Depth Electives (required)

Five depth electives (required), to be chosen from the list below. The course 21-355 is particularly recommended for a student planning to pursue graduate work.

Courses		Units
15-122	Principles of Imperative Computation	10
15-150	Principles of Functional Programming	10
15-210	Parallel and Sequential Data Structures and Algorithms	12
21-270	Introduction to Mathematical Finance	9
21-301	Combinatorics	9
21-341	Linear Algebra	9
21-355	Principles of Real Analysis I	9
21-356	Principles of Real Analysis II	9
21-365	Projects in Applied Mathematics	9
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
21-420	Continuous-Time Finance	9
21-484	Graph Theory	9
36-461	Special Topics: Statistical Methods in Epidemiology	9
36-462	Special Topics: Data Mining	9
36-463	Special Topics: Multilevel and Hierarchical Models	9
36-464	Special Topics: Applied Multivariate Methods	9
70-371	Operations Management	9
70-460	Mathematical Models for Consulting	9
70-471	Supply Chain Management	9

MCS General Education (required)

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

Note that 73-102, 73-230, and 73-240 satisfy requirements from the MCS general education core.

Suggested Schedule

Freshman Year

Fall		Units
21-120	Differential and Integral Calculus	10
21-127	Concepts of Mathematics	10
or 21-128	Mathematical Concepts and Proofs	
38-101	First-year Seminar	6
76-101	Interpretation and Argument	9
99-101	Computing @ Carnegie Mellon	3
xx-xxx	Life/Physical Sciences Course	9
		47

Spring		Units
15-110	Principles of Computing	10
or 15-112	Fundamentals of Programming and Computer Science	
21-122	Integration and Approximation	10
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
xx-xxx	Physical/Life Sciences Course	9
xx-xxx	H&SS Elective	9
		48

Sophomore Year

Fall		Units
21-228	Discrete Mathematics	9
or 15-251	Great Ideas in Theoretical Computer Science	
21-259	Calculus in Three Dimensions	9
or 21-268	Multidimensional Calculus	
or 21-269	Vector Analysis	
73-102	Principles of Microeconomics	9
xx-xxx	STEM Course	9
		36

Spring		Units
21-260	Differential Equations	9
or 21-261	Introduction to Ordinary Differential Equations	
or 33-231	Physical Analysis	
21-292	Operations Research I	9
70-122	Introduction to Accounting	9
xx-xxx	H&SS Elective	9
xx-xxx	STEM Elective	9
		45

Junior Year

Fall		Units
21-369	Numerical Methods	9
36-225	Introduction to Probability Theory	9
or 21-325	Probability	
73-103	Principles of Macroeconomics	9
xx-xxx	Depth Elective	9
xx-xxx	Free Elective	9
		45

Spring		Units
36-226	Introduction to Statistical Inference	9
36-410	Introduction to Probability Modeling	9
xx-xxx	Depth Elective	9
73-230	Intermediate Microeconomics	9
or 73-240	Intermediate Macroeconomics	
xx-xxx	Cultural/Global Understanding Course	9
		45

Senior Year

Fall		Units
21-393	Operations Research II	9
36-401	Modern Regression	9
xx-xxx	Depth Elective	9
xx-xxx	H&SS Elective	9
xx-xxx	Free Elective	9
		45

Spring		Units
36-402	Advanced Methods for Data Analysis	9
xx-xxx	Depth Elective	9
xx-xxx	Depth Elective	9
xx-xxx	H&SS Elective	9
xx-xxx	Free Elective	9
		45

Minimum number of units required for degree: 360

Statistics Concentration

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 36-225 Introduction to Probability Theory 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 36-225.

The Statistics Concentration is jointly administered by the Department of Mathematical Sciences and the Department of Statistics and Data Science. The Department of Statistics and Data Science considers applications for the master's program from undergraduates in the Junior year. Students who are accepted are expected to finish their undergraduate studies, using some electives in the Senior year to take courses recommended by the Department of Statistics and Data Science. This will ensure a strong background to permit completion of the master's program in one year beyond the baccalaureate. 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	10
or 21-128	Mathematical Concepts and Proofs	
21-228	Discrete Mathematics	9
or 15-251	Great Ideas in Theoretical Computer Science	
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
21-259	Calculus in Three Dimensions	9
or 21-268	Multidimensional Calculus	
or 21-269	Vector Analysis	
21-260	Differential Equations	9
or 21-261	Introduction to Ordinary Differential Equations	
or 33-231	Physical Analysis	
21-292	Operations Research I	9
21-369	Numerical Methods	9
Starting Fall 2018, 21-369 will be 12 units with recitation.		
21-393	Operations Research II	9
		94

Statistics Courses (required)

Courses		Units
36-225	Introduction to Probability Theory	9
or 21-325	Probability	
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

Economics and Computer Science Courses (required)

Courses		Units
15-112	Fundamentals of Programming and Computer Science	12
15-122	Principles of Imperative Computation	10
73-102	Principles of Microeconomics	9
		31

Depth Electives (required)

Five depth electives, including at least one statistics course, to be chosen from the list below. The course 21-355 Principles of Real Analysis I is particularly recommended for a student planning to pursue graduate work.

Courses		Units
15-150	Principles of Functional Programming	10
15-210	Parallel and Sequential Data Structures and Algorithms	12
21-270	Introduction to Mathematical Finance	9
21-341	Linear Algebra	9
21-355	Principles of Real Analysis I	9
21-356	Principles of Real Analysis II	9
21-365	Projects in Applied Mathematics	9
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
21-420	Continuous-Time Finance	9
21-484	Graph Theory	9
36-461	Special Topics: Statistical Methods in Epidemiology	9
36-462	Special Topics: Data Mining	9
36-463	Special Topics: Multilevel and Hierarchical Models	9
36-464	Special Topics: Applied Multivariate Methods	9

MCS General Education (required)

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

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

Suggested Schedule

Freshman Year

Fall		Units
21-120	Differential and Integral Calculus	10
21-127	Concepts of Mathematics	10
or 21-128	Mathematical Concepts and Proofs	
38-101	First-year Seminar	6
76-101	Interpretation and Argument	9
99-101	Computing @ Carnegie Mellon	3
xx-xxx	Life/Physical Sciences Course	9
		47

Spring		Units
15-112	Fundamentals of Programming and Computer Science	12
21-122	Integration and Approximation	10
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
xx-xxx	STEM Course	9
xx-xxx	Physical/Life Sciences Course	9
		50

Sophomore Year

Fall		Units
21-228	Discrete Mathematics	9
or 15-251	Great Ideas in Theoretical Computer Science	
21-259	Calculus in Three Dimensions	9
or 21-268	Multidimensional Calculus	
or 21-269	Vector Analysis	
73-102	Principles of Microeconomics	9
xx-xxx	STEM Course	9
xx-xxx	H&SS Elective	9
		45

Spring		Units
15-122	Principles of Imperative Computation	10

21-260	Differential Equations	9
or 21-261	Introduction to Ordinary Differential Equations	
or 33-231	Physical Analysis	
21-292	Operations Research I	9
xx-xxx	H&SS Elective	9
xx-xxx	Free Elective	9
		46

Junior Year

Fall		Units
21-369	Numerical Methods	9
36-225	Introduction to Probability Theory	9
or 21-325	Probability	
xx-xxx	Depth Elective	9
xx-xxx	Depth Elective	9
xx-xxx	H&SS Elective	9
		45

Spring		Units
36-226	Introduction to Statistical Inference	9
36-410	Introduction to Probability Modeling	9
xx-xxx	Depth Elective	9
xx-xxx	Cultural/Global Understanding Course	9
xx-xxx	Free Elective	9
		45

Senior Year

Fall		Units
21-393	Operations Research II	9
36-401	Modern Regression	9
xx-xxx	Depth Elective	9
xx-xxx	H&SS Elective	9
xx-xxx	Free Elective	9
		45

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: 360

Discrete Mathematics and Logic Concentration

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.

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	10
15-150	Principles of Functional Programming	10
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	10
or 21-128	Mathematical Concepts and Proofs	
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
21-300	Basic Logic	9
or 15-317	Constructive Logic	
21-228	Discrete Mathematics	9
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
21-373	Algebraic Structures	9
		126

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 two additional Computer Science courses at the 300 level or above to avoid excessive double counting.

Mathematical Sciences Electives (required)

Seven courses from lists 1 and 2 below, including at least three chosen from list 1.

List 1 (Discrete Mathematics and Logic Electives)

Courses		Units
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
80-405	Game Theory	9
80-411	Proof Theory	9
80-413	Category Theory	9

List 2 (General Mathematics Electives)

Courses		Units
21-259	Calculus in Three Dimensions	9-10
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	
21-272	Introduction to Partial Differential Equations	9
21-292	Operations Research I	9
21-356	Principles of Real Analysis II	9
21-366	Topics in Applied Mathematics	9
21-369	Numerical Methods	9
Starting Fall 2018, 21-369 will be 12 units with recitation.		
21-370	Discrete Time Finance	9
21-371	Functions of a Complex Variable	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
21-499	Undergraduate Research Topic	9
Any graduate course in mathematics at the 600 and 700 level not included in List 1.		

MCS General Education (required)

MCS or SHS 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	First-year Seminar	6
76-101	Interpretation and Argument	9
99-101	Computing @ Carnegie Mellon	3
xx-xxx	Life/Physical Sciences Course	9
		49

Spring		Units
15-122	Principles of Imperative Computation	10
21-122	Integration and Approximation	10
21-127	Concepts of Mathematics	10
or 21-128	Mathematical Concepts and Proofs	
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
xx-xxx	Physical/Life Sciences Course	9
		49

Sophomore Year

Fall		Units
15-150	Principles of Functional Programming	10
21-268	Multidimensional Calculus	10
or 21-269	Vector Analysis	
21-301	Combinatorics	9
21-373	Algebraic Structures	9
xx-xxx	H&SS Elective	9
		47

Spring		Units
15-210	Parallel and Sequential Data Structures and Algorithms	12
xx-xxx	Discrete Math/Logic Elective	9
xx-xxx	Mathematics Elective	9
xx-xxx	STEM Course	9
xx-xxx	H&SS Elective	9
		48

Junior Year

Fall		Units
15-xxx	Computer Science Elective	9
21-300	Basic Logic	9
or 15-317	Constructive Logic	
21-355	Principles of Real Analysis I	9
xx-xxx	H&SS Elective	9
xx-xxx	STEM Course	9
		45

Spring		Units
15-xxx	Computer Science Elective	9
21-341	Linear Algebra	9
xx-xxx	H&SS Elective	9
xx-xxx	Cultural/Global Understanding Course	9
xx-xxx	Free Elective	9
		45

Senior Year

Fall		Units
xx-xxx	Discrete Math/Logic Elective	9
xx-xxx	Mathematics Elective	9
xx-xxx	Mathematics Elective	9
xx-xxx	Free Elective	9
xx-xxx	Free Elective	9
		45

Spring		Units
xx-xxx	Discrete Math/Logic Elective	9
xx-xxx	Mathematics Elective	9
xx-xxx	Mathematics Elective	9
xx-xxx	Free Elective	9
xx-xxx	Free Elective	9
		45

Minimum number of units required for degree: 360

Computational and Applied Mathematics Concentration

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.

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	10
or 21-128	Mathematical Concepts and Proofs	
21-228	Discrete Mathematics	9
or 15-251	Great Ideas in Theoretical Computer Science	
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
21-259	Calculus in Three Dimensions	9
or 21-268	Multidimensional Calculus	
or 21-269	Vector Analysis	
21-260	Differential Equations	9
or 21-261	Introduction to Ordinary Differential Equations	
or 33-231	Physical Analysis	
36-225	Introduction to Probability Theory	9
or 21-325	Probability	
21-272	Introduction to Partial Differential Equations	9
21-355	Principles of Real Analysis I	9
21-369	Numerical Methods	9
Starting Fall 2018, 21-369 will be 12 units with recitation.		
		103

Two courses from:

Courses		Units
21-341	Linear Algebra	9
21-356	Principles of Real Analysis II	9
21-380	Introduction to Mathematical Modeling	9
21-435	Applied Harmonic Analysis	9
21-469	Numerical Methods II: Scientific Computing	9

Computer Science Courses (required)

Courses		Units
15-122	Principles of Imperative Computation	10

Mathematics Electives (required)

Students must take 36 units either from the three remaining courses in List 1 or from the list below:

Courses		Units
21-292	Operations Research I	9
21-365	Projects in Applied Mathematics	9
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
21-393	Operations Research II	9
21-420	Continuous-Time Finance	9
21-467	Differential Geometry	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
21-724	Sobolev Spaces	12
21-732	Partial Differential Equations I	12
21-832	Partial Differential Equations II	12

Students must take 9 additional units of Mathematical Sciences (at the 21-300 level or above or 21-270 or 21-272 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 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 21-499 Undergraduate Research Topic and 21-599 Undergraduate Reading and Research for this purpose. These courses can be taken as part of satisfying the Depth Elective requirement, but require permission of both the instructor and the department.

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

MCS General Education (required)

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

Students not in MCS are required to take 15-110 Principles of Computing (10 units).

Suggested Schedule

Freshman Year

Fall		Units
21-120	Differential and Integral Calculus	10
21-126	Introduction to Mathematical Software	3
21-127	Concepts of Mathematics	10
or 21-128	Mathematical Concepts and Proofs	
38-101	First-year Seminar	6
76-101	Interpretation and Argument	9
xx-xxx	Life/Physical Sciences Course	9
		47

Spring		Units
21-122	Integration and Approximation	10
21-228	Discrete Mathematics	9
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
xx-xxx	Physical/Life Sciences Course	9
xx-xxx	H&SS Elective	9
		47

Sophomore Year

Fall		Units
15-112	Fundamentals of Programming and Computer Science	12
21-268	Multidimensional Calculus	10
or 21-269	Vector Analysis	
xx-xxx	STEM Course	9
xx-xxx	H&SS Elective	9
xx-xxx	Free Elective	9
		49

Spring		Units
15-122	Principles of Imperative Computation	10
21-261	Introduction to Ordinary Differential Equations	10
21-355	Principles of Real Analysis I	9
xx-xxx	STEM Course	9
xx-xxx	H&SS Elective	9
		47

Junior Year

Fall		Units
21-320	Symbolic Programming Methods	9
21-325	Probability	9
21-356	Principles of Real Analysis II	9
xx-xxx	H&SS Elective	9
xx-xxx	Free Elective	9
		45

Spring		Units
xx-xxx	Mathematics Elective	9
21-369	Numerical Methods	9
xx-xxx	Depth Elective	9
xx-xxx	Cultural/Global Understanding Elective	9
xx-xxx	Free Elective	9
		45

Senior Year

Fall		Units
xx-xxx	Mathematics Elective	9
xx-xxx	Mathematics Elective	9
xx-xxx	Free Elective	9
xx-xxx	Free Elective	9
xx-xxx	Free Elective	9
		45

Spring		Units
xx-xxx	Mathematics Elective	9
xx-xxx	Free Elective	9
xx-xxx	Free Elective	9
xx-xxx	Free Elective	9
xx-xxx	Free Elective	9
		45

Minimum number of units required for degree: 360

Double Major Requirements

All degrees offered by the Department are available as a second major to students majoring in other departments. Interested students should contact the Department for further information and guidance. In general the requirements for a second major include all the required courses except the MCS core and free electives.

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.

21-127	Concepts of Mathematics	10
21-228	Discrete Mathematics	9-12
or 15-251	Great Ideas in Theoretical Computer Science	
21-241	Matrices and Linear Transformations	10
or 21-242	Matrix Theory	
21-355	Principles of Real Analysis I	9
21-3xx	Mathematical Sciences Elective	
21-3xx	Mathematical Sciences Elective	

To avoid excessive double counting, the two Mathematical Sciences Electives may not also count toward the student's major.

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

[1]21-127 Concepts of Mathematics is a prerequisite for 21-228.

Three of the following (at least one from each group):

Logic		
21-329	Set Theory	9
21-400	Intermediate Logic	9
21-602	Introduction to Set Theory I	12
21-603	Model Theory I	12
21-700	Mathematical Logic II	12
Algebra and Discrete Mathematics		
21-341	Linear Algebra	9
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 leads to an M.S. in Mathematical Sciences, normally in four years, in addition to the student's B.S. degree. The key element in the program is usually the Mathematical Studies sequence. Admission to the Honors Program, in the Junior year, requires an application while admission to the Math Studies sequences is by invitation only. Students with a grade of B or higher in 21-235 Mathematical Studies Analysis I will be allowed to register for 21-236 Mathematical Studies Analysis II. Students with a grade of B or higher in 21-237 Mathematical Studies Algebra I will be allowed to register for 21-238 Mathematical Studies Algebra II . In the application process the Department will hold to the same high standards which apply to admission to any graduate program.

The core undergraduate honors courses are:

Freshman Year

Fall		Units
21-242	Matrix Theory (Honors version of 21-241 Matrices and Linear Transformations)	10
Spring		
21-269	Vector Analysis (Honors version of 21-268 Multidimensional Calculus)	10

Sophomore Year

Fall		
21-235	Mathematical Studies Analysis I	12
21-237	Mathematical Studies Algebra I (Honors version of 21-373 Algebraic Structures)	12
Spring		
21-236	Mathematical Studies Analysis II (Honors version of 21-356 Principles of Real Analysis II)	12
21-238	Mathematical Studies Algebra II (Honors version of 21-341 Linear Algebra)	12

Honors Program Requirements:

21-901	Masters Degree Research	Var.

Five graduate mathematics courses: 60 units

Each student in the honors degree program will have a thesis advisor in addition to his or her academic advisor. In practice, the student must start thinking about the thesis as early as possible. For this reason we include some thesis work, 3 units of 21-901 Masters Degree Research, in the Fall semester of the Senior year to allow for exploratory work under supervision. The actual thesis work is then planned for the final semester with 15 units of 21-901 Masters Degree Research. The student must give a public presentation and will be examined on the thesis and related mathematics.

The five graduate courses must include at least one course from each of the following areas:

- Analysis: for example, Measure and Integration, Complex Analysis, Functional Analysis
- Algebra, Logic, Geometry and Topology: for example, Mathematical Logic I, Algebra I, General Topology, Discrete Mathematics, Commutative Algebra, Differential Geometry
- Applied Mathematics: for example, Introduction to Continuum Mechanics, Probability Measures, Probability Theory, Graphs and Network Flows, Ordinary Differential Equations, Methods of Optimization, Introduction to Numerical Analysis I, Partial Differential Equations I, Sobolev Spaces.

Faculty

PETER B. ANDREWS, Emeritus – Ph.D., Princeton University; Carnegie Mellon, 1963–.

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

EGON BALAS, University Professor – Ph.D., University of Brussels; Carnegie Mellon, 1968–.

ALBERT A. BLANK, Emeritus – Ph.D., New York University; Carnegie Mellon, 1969–.

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

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