Mathematics

The Mathematics Department at Brown balances a lively interest in students and teaching with a distinguished research reputation. Our several strong research groups, Analysis, Algebraic Geometry, Geometry and Topology, and Number Theory, all have active seminar schedules that draw local and international speakers. The undergraduate program in mathematics is designed to present students with challenging courses that will train them for any future they desire, be it in the economy, the government, or academe. We are also quite flexible in placing students; our goal being to discover a student's level of competence and then offering a stimulating course.

We support 40+ graduate students in a Ph.D. program whose graduates populate top mathematics departments and prominent positions in industry. Our joint graduate courses and seminars with the adjacent Division of Applied Mathematics add to the breadth of offerings available to our graduate students.

For additional information, please visit the department's website: https://www.brown.edu/academics/math/

Mathematics Concentration Requirements

Mathematics is a grouping of sciences, including geometry, algebra, and calculus, that study quantity, structure, space, and change. Mathematics concentrators at Brown can explore these concepts through the department’s broad course offerings and flexible concentration requirements. The concentration leads to either the Bachelor of Arts or Bachelor of Science degree (the latter is strongly recommended for students interested in pursuing graduate study in mathematics or related fields). Concentrators begin their learning with multivariable calculus, linear algebra, and abstract algebra. Beyond these prerequisites, students take a variety of advanced topics on the 1000 level based on their interests. After sufficient preparation and with permission of the instructor, students may also take courses on the 2000 level. Students also have the option of completing a thesis project.

Concentrators in mathematics should complete the prerequisites by the end of their sophomore year. It is strongly recommended that students take MATH 1010 before taking MATH 1630, (formerly MATH 1130).

Standard program for the A.B. degree

Prerequisites:		
Multivariable calculus and linear algebra (choose one of the following sequences):		2
MATH 0180 & MATH 0520	Multivariable Calculus and Linear Algebra	
MATH 0180 & MATH 0540	Multivariable Calculus and Linear Algebra With Theory	
MATH 0200 & MATH 0520	Multivariable Calculus (Physics/ Engineering) and Linear Algebra	
MATH 0350 & MATH 0540	Multivariable Calculus With Theory and Linear Algebra With Theory	
Or the equivalent		
Program:		
MATH 1530	Abstract Algebra	1
Five other 1000- or 2000-level Mathematics courses . The year-long sequence 0750/0760 may be substituted for one of these course credits.		5
Total Credits		**8**

Standard program for the Sc.B. degree

Prerequisites:		
Multivariate calculus and linear algebra (choose one of the following sequences):		2
MATH 0180 & MATH 0520	Multivariable Calculus and Linear Algebra	
MATH 0180 & MATH 0540	Multivariable Calculus and Linear Algebra With Theory	
MATH 0200 & MATH 0520	Multivariable Calculus (Physics/ Engineering) and Linear Algebra	
MATH 0350 & MATH 0540	Multivariable Calculus With Theory and Linear Algebra With Theory	
Or the equivalent		
Program:		
MATH 1630	Real Analysis I (formerly MATH 1130)	1
MATH 1640	Real Analysis II (formerly MATH 1140)	1
MATH 1530	Abstract Algebra	1
MATH 1540	Topics in Abstract Algebra	1
or MATH 1560	Number Theory	
Four other 1000- or 2000- level Mathematics courses. The year-long sequence 0750/0760 may be substituted for one of these course credits.		4
Four additional courses in mathematics, science, economics, or applied mathematics approved by the concentration advisor.		4
Total Credits		**14**

Honors

Honors degrees may be recommended for students who have exhibited high achievement in mathematics. Candidates must complete at least eight mathematics courses at the 1000 or 2000 level with sufficiently good grades and must write an honors thesis under the guidance of a faculty member. The honors thesis is usually written while the candidate is enrolled in MATH 1970. The candidate should consult with the concentration advisor for the precise grade requirements.

Those interested in graduate study in mathematics are encouraged to take:

MATH 1630	Real Analysis I (formerly MATH 1130)
MATH 1640	Real Analysis II (formerly MATH 1140)
MATH 1460	Complex Analysis (formerly MATH 1260)
MATH 1710	Topology (formerly MATH 1410)
MATH 1540	Topics in Abstract Algebra

Mathematics-Computer Science Concentration Requirements

Students may opt to pursue an interdisciplinary Bachelor of Science degree in Math-Computer Science, a concentration administered cooperatively between the mathematics and computer science departments. Course requirements include math- and systems-oriented computer science courses, as well as computational courses in applied math. Students must identify a series of electives that cohere around a common theme. As with other concentrations offered by the Computer Science department, students have the option to pursue the professional track (http://www.cs.brown.edu/ugrad/concentrations/professional.track.html) of the ScB program in Mathematics-Computer Science.

Requirements for the Standard Track of the Sc.B. degree.

Prerequisites		
Three semesters of Calculus to the level of MATH 0180, MATH 0200, or MATH 0350		3
MATH 0520	Linear Algebra	1
or MATH 0540	Linear Algebra With Theory	
or CSCI 0530	Coding the Matrix: An Introduction to Linear Algebra for Computer Science	
Core Courses		

MATH 1530	Abstract Algebra	1
Select one of the following series:		2
Series A		
CSCI 0150 & CSCI 0200	Introduction to Object-Oriented Programming and Computer Science and Program Design with Data Structures and Algorithms	
Series B		
CSCI 0170 & CSCI 0200	Computer Science: An Integrated Introduction and Program Design with Data Structures and Algorithms	
Series C		
CSCI 0190	Accelerated Introduction to Computer Science (and an additional CS course not otherwise used to satisfy a concentration requirement; an intermediate-level CS course, or a 1000-level CS course)	
Series D [1]		
CSCI 0111 & CSCI 0112 & CSCI 0200	Computing Foundations: Data and Computing Foundations: Program Organization and Program Design with Data Structures and Algorithms	
Intermediate Courses: Two courses from the following:		2
a. Algorithms/Theory Foundations		
CSCI 0500	Data Structures, Algorithms, and Intractability: An Introduction	
CSCI 1010	Theory of Computation	
CSCI 1550	Probabilistic Methods in Computer Science	
CSCI 1570	Design and Analysis of Algorithms	
b. AI/Machine Learning/Data Science Foundations		
CSCI 1410	Artificial Intelligence	
or CSCI 1420	Machine Learning	
or CSCI 1430	Computer Vision	
or CSCI 1460	Computational Linguistics	
or CSCI 1470	Deep Learning	
or CSCI 1850	Deep Learning in Genomics	
or CSCI 1951R	Introduction to Robotics	
c. Systems Foundations		
CSCI 0300	Fundamentals of Computer Systems	
or CSCI 0330	Introduction to Computer Systems	
Three 1000-level Mathematics courses which cannot inlude arts/policy/jumanities courses. One of these can be an additional Foundations Course		3
Three advanced courses in Computer Science [2,3]		3
Three additional courses different from any of the above chosen from Mathematics, Computer Science, Applied Mathematics, or related areas [4]		3
A capstone course in Computer Science or Mathematics [5]		1
Total Credits		**19**

1 Students wishing to go directly from CSCI 0111 to CSCI 0200 (without CSCI 0112) will need to successfully complete additional exercises to receive an instructor override code for CSCI 0200. In 2020-21, these exercises will be offered within CSCI 0111. Students from prior CSCI 0111 offerings should contact the current CSCI0111 instructor to arrange to do this work.

2 These must be CSCI courses at the 1000-level or higher. Two of these courses and the intermediate courses must satisfy one of the CS pathways (https://cs.brown.edu/degrees/undergrad/concentrating-in-cs/concentration-requirements-2020/pathways-for-undergraduate-and-masters-students/. At most one arts, humanities, or social science CS course can be used for concentration credit (currently CSCI 1250, 1280, 1360, 1370, 1800, 1805, 1870, 1952B, 1952X, 2002, 2952S).

3 Note: CSCI 1010 may be used either as a math-oriented intermediate course or as an advanced course. CSCI 1010 was formerly known as CSCI 510: they are the same course and hence only one may be taken for credit. CSCI 1450 was formerly known as CSCI 450: they are the same course and hence only one may be taken for credit. Applied Math 1650 or 1655 may be used in place of CSCI 1450 in CS pathway requirements (https://cs.brown.edu/degrees/undergrad/concentrating-in-cs/concentration-requirements-2020/pathways-for-undergraduate-and-masters-students/). However, concentration credit will be given for only one of Applied Math 1650, 1655, and CSCI 1450.

4 These must be approved by a concentration advisor.

5 A one-semester course, taken in the student's last undergraduate year, in which the student (or group of students) use a significant portion of their undergraduate education, broadly interpreted, in studying some current topic in depth, to produce a culminating artifact such as a paper or software project. The title and abstract of the artifact, along with the student's and faculty-sponsor's names, will be placed in the CS website. The inclusion of a relevant image or system diagram is strongly encouraged. The complete text of the best artifacts of each class will be featured on the CS website. A senior thesis, which involves two semesters of work, may count as a capstone Course-based capstones are currently only available through CS. Approved capstone courses and instructions may be found here: https://cs.brown.edu/degrees/undergrad/concentrating-in-cs/concentration-requirements-2020/capstone/

Requirements for the Professional Track of the Sc.B. degree.

The requirements for the professional track include all those of the standard track, as well as the following:

Students must complete full-time professional experiences doing work that is related to their concentration programs, totaling 2-6 months, whereby each internship must be at least one month in duration in cases where students choose to do more than one internship experience. Such work is normally done at a company, but may also be at a university under the supervision of a faculty member. Internships that take place between the end of the fall and the start of the spring semesters cannot be used to fulfill this requirement.

On completion of each professional experience, the student must write and upload to ASK a reflective essay about the experience addressing the following prompts, to be approved by the student's concentration advisor:

- Which courses were put to use in your summer's work? Which topics, in particular, were important?
- In retrospect, which courses should you have taken before embarking on your summer experience? What are the topics from these courses that would have helped you over the summer if you had been more familiar with them?
- Are there topics you should have been familiar with in preparation for your summer experience, but are not taught at Brown? What are these topics?
- What did you learn from the experience that probably could not have been picked up from course work?
- Is the sort of work you did over the summer something you would like to continue doing once you graduate? Explain.
- Would you recommend your summer experience to other Brown students? Explain.

Mathematics-Economics Concentration Requirements

The Mathematics Economics concentration is designed to give a background in economic theory plus the mathematical tools needed to analyze and develop additional theoretical constructions. The emphasis is on the abstract theory itself. Students may choose either the standard or the professional track, both award a Bachelor of Arts degree. If you are interested in declaring a concentration in Mathematics Economics, please refer to this page (https://economics.brown.edu/academics/undergraduate/concentrations/declaring/) for more information regarding the process.

Standard Mathematics-Economics Concentration

Economics		
ECON 1130	Intermediate Microeconomics (Mathematical) [1]	1
ECON 1210	Intermediate Macroeconomics	1
ECON 1630	Mathematical Econometrics I	1
Two courses from the "mathematical-economics" group: [2]		2
ECON 1170	Welfare Economics and Social Choice Theory	
ECON 1225	Advanced Macroeconomics: Monetary, Fiscal, and Stabilization Policies	
ECON 1255	Unemployment: Models and Policies	
ECON 1470	Bargaining Theory and Applications	
ECON 1490	Theory of Market Design	
ECON 1545	Topics in Macroeconomics, Development and International Economics	
ECON 1640	Mathematical Econometrics II	
ECON 1660	Big Data	
ECON 1670	Advanced Topics in Econometrics	
ECON 1680	Machine Learning, Text Analysis, and Economics	
ECON 1750	Investments II	
ECON 1770	Crisis Economics	
ECON 1805	Economics in the Laboratory	
ECON 1820	Theory of Behavioral Economics	
ECON 1860	The Theory of General Equilibrium	
ECON 1870	Game Theory and Applications to Economics	
One course from the "data methods" group: [2]		1
ECON 1301	Economics of Education I	
ECON 1310	Labor Economics	
ECON 1315	Health, Education, and Social Policy	
ECON 1340	Economics of Global Warming	
ECON 1355	Environmental Issues in Development Economics	
ECON 1360	Health Economics	
ECON 1375	Inequality of Opportunity in the US	
ECON 1385	Intergenerational Poverty in America	
ECON 1400	The Economics of Mass Media	
ECON 1430	The Economics of Social Policy	
ECON 1510	Economic Development	
ECON 1530	Health, Hunger and the Household in Developing Countries	
ECON 1629	Applied Research Methods for Economists	
ECON 1640	Mathematical Econometrics II	
ECON 1660	Big Data	
ECON 1670	Advanced Topics in Econometrics	
ECON 1680	Machine Learning, Text Analysis, and Economics	
ECON 1825	Behavioral Economics and Public Policy	
ECON 1830	Behavioral Finance	
Two additional 1000-level economics courses [3]		2
Mathematics		
Calculus: MATH 0180 or higher		1
Linear Algebra - one of the following:		1
MATH 0520	Linear Algebra	
MATH 0540	Linear Algebra With Theory	
Probability Theory - one of the following:		1
MATH 1210	Probability (Formerly MATH 1610)	
MATH 1620	Mathematical Statistics	
APMA 1650	Statistical Inference I	
Analysis - one of the following:		1
MATH 1010	Analysis: Functions of One Variable	
MATH 1630	Real Analysis I (Formerly MATH 1130)	
MATH 1640	Real Analysis II (Formerly MATH 1140)	
Differential Equations - one of the following:		1
MATH 1110	Ordinary Differential Equations	
MATH 1120	Partial Differential Equations	
One additional course from the Probability, Analysis, and Differential Equations courses listed above		1
Total Credits		**14**

1. Or ECON 1110 with permission. For students matriculating at Brown in Fall 2021 or later, note that if ECON 1110 is used, then one additional course from the mathematical-economics group will be required
2. No course may be "double-counted" to satisfy both the mathematical-economics and data methods requirement.
3. Students may apply, at most, one Economics course whose number is in the range of 1000 to 1099 toward the concentration. Note that ECON 1620, ECON 1960, and ECON 1970 (independent study) cannot be used for concentration credit. However, ECON 1620 and ECON 1960 can be used for university credit and up to two 1970s may be used for university credit.
4. MATH 1630 (formerly MATH 1130) is a prerequisite for MATH 1640 (formerly MATH 1140).

Honors:

Students who meet stated requirements are eligible to write an honors thesis in their senior year. Students should consult the listed honors requirements of whichever of the two departments their primary thesis advisor belongs to, at the respective departments' websites.

Professional Track:

The requirements for the professional track include all those of the standard track, as well as the following:

Students must complete full-time professional experiences doing work that is related to their concentration programs, totaling 2-6 months, whereby each internship must be at least one month in duration in cases where students choose to do more than one internship experience. Such work is normally done at a company, but may also be at a university under the supervision of a faculty member. Internships that take place between the end of the fall and the start of the spring semesters cannot be used to fulfill this requirement.

On completion of each professional experience, the student must write and upload to ASK a reflective essay about the experience addressing the following prompts, to be approved by the student's concentration advisor:

- Which courses were put to use in your summer's work? Which topics, in particular, were important?
- In retrospect, which courses should you have taken before embarking on your summer experience? What are the topics from these courses that would have helped you over the summer if you had been more familiar with them?
- Are there topics you should have been familiar with in preparation for your summer experience, but are not taught at Brown? What are these topics?
- What did you learn from the experience that probably could not have been picked up from course work?

- Is the sort of work you did over the summer something you would like to continue doing once you graduate? Explain.
- Would you recommend your summer experience to other Brown students? Explain.

Mathematics Graduate Program

The Math Department PhD program is intended for students with a solid background in undergraduate mathematics and a strong interest in research. Most of our students intend to pursue academic careers or find other kinds of positions, for example in industry or finance.

We aim to provide a supportive environment for teaching, learning, and creating mathematics. The relatively small size (about 40+ graduate students and 25+ faculty and postdocs) allows for close contact with faculty and a sense of community. The program is flexible enough to accommodate a range of levels of preparation. More than 85% of students admitted receive their PhD.

For more information on admission and program requirements, please visit the following website:

https://www.brown.edu/academics/math/graduate (https://www.brown.edu/academics/math/graduate/)

Courses

MATH 0010A. First Year Seminar: A Taste of the Infinite.
The concept of infinity occurs in many disciplines - philosophy, mathematics, physics, religion, art, and so on. This class will focus on the mathematical aspects of infinity, surveying some of the ways that the infinite arises in mathematics. Topics will include: the sizes of infinity, rates of growth, computational complexity, construction of the real numbers, the notion of compactness, geometric spaces, transcendental numbers, and fractal sets. I will not assume any prior knowledge of mathematics beyond a good grounding in high school algebra and geometry.

MATH 0010B. Exploring the Fourth Dimension.
This interdisciplinary seminar explores all the mathematics students have seen or ever will see, concentrating on an engaging topic that begins with elementary geometry and branches out to literature, history, philosophy, and art as well as physics and other sciences. Guideposts to the fourth dimension include Salvador Dali's Corpus Hypercubicus, Edwin Abbott Abbott's Flatland, and Jeff Weeks' The Shape of Space. Students will investigate new mathematical topics such as combinatorics, regular polytopes, topology, and non-Euclidean geometry. Although students will use computers for visualization, no computer experience is required. There are no specific mathematical prerequisites except curiosity and a willingness to participate actively. Students considering concentrations in humanities, social sciences, and the arts are especially invited to this first-year seminar. Enrollment limited to 19 first year students.

MATH 0010C. From 'Flatland' to the Fourth Dimension.
No description available. Enrollment limited to 15 first year students. Instructor permssion required, after initial placement of students.

MATH 0050. Analytic Geometry and Calculus.
MATH 0050 and 0060 provide a slower-paced introduction to calculus for students who require additional preparation. Presents the same calculus topics as MATH 0090, together with a review of the necessary precalculus topics. Students successfully completing this sequence are prepared for MATH 0100. S/NC only.

Fall	MATH0050	S01	10139	TTh	9:00-10:20(05)	'To Be Arranged'
Fall	MATH0050	C01	17601	Th	12:00-12:50	'To Be Arranged'

MATH 0060. Analytic Geometry and Calculus.
A slower-paced introduction to calculus for students who require additional preparation. Presents the same calculus topics as MATH 0090, together with a review of the necessary precalculus topics. Students successfully completing this sequence are prepared for MATH 0100. Prerequisite: MATH 0050 or written permission. May not be taken for credit in addition to MATH 0070 or MATH 0090. S/NC only.

Spr	MATH0060	S01	20112	MWF	9:00-9:50(02)	'To Be Arranged'
Spr	MATH0060	C01	25861	Th	12:00-12:50	'To Be Arranged'

MATH 0070. Calculus with Applications to Social Science.
A survey of calculus for students who wish to learn the basics of calculus for application to social sciences or for cultural appreciation as part of a broader education. Topics include functions, equations, graphs, exponentials and logarithms, and differentiation and integration; applications such as marginal analysis, growth and decay, optimization, and elementary differential equations. May not be taken for credit in addition to MATH 0060 or MATH 0090. S/NC only.

MATH 0081. Math Teaching Fellows Program.
The Math Teaching Fellows Program is a semester-long certificate program that provides UTAs with the skills and knowledge required to be an effective UTA in the Math Department. Admission into the program is by application only; participants will hold a UTA appointment in a Mathematics course approved by the Teaching Fellows Coordinators and must therefore be eligible for student employment at Brown during the term. Participants should have completed at least one of Math 0100, 0180, 0190, 0200, 0350, 0520, 0540.

MATH 0090. Single Variable Calculus, Part I.
An intensive course in calculus of one variable including limits, differentiation, maxima and minima, the chain rule, rational functions, trigonometric functions, and exponential functions. Introduction to integration with applications to area and volumes of revolution. MATH 0090 and MATH 0100 or the equivalent are recommended for all students intending to concentrate in the sciences or mathematics. May not be taken for credit in addition to MATH 0060 or MATH 0070. S/NC only.

Fall	MATH0090	S01	10140	MWF	9:00-9:50(09)	'To Be Arranged'
Fall	MATH0090	S02	10141	MWF	10:00-10:50(14)	(D. Katz)
Fall	MATH0090	S03	10142	MWF	11:00-11:50(16)	(P. Zenz)
Fall	MATH0090	S04	10143	MWF	12:00-12:50(15)	'To Be Arranged'
Fall	MATH0090	S05	10144	TTh	9:00-10:20(05)	'To Be Arranged'
Fall	MATH0090	C01	17472	Th	2:30-3:50	'To Be Arranged'
Fall	MATH0090	C02	17473	Th	9:00-10:20	'To Be Arranged'
Fall	MATH0090	C03	17474	Th	9:00-10:20	'To Be Arranged'
Fall	MATH0090	C04	17475	Th	10:30-11:50	'To Be Arranged'
Fall	MATH0090	C05	17476	Th	10:30-11:50	'To Be Arranged'
Fall	MATH0090	C06	17477	Th	1:00-2:20	'To Be Arranged'
Fall	MATH0090	C07	17478	Th	1:00-2:20	'To Be Arranged'
Fall	MATH0090	C08	17479	Th	2:30-3:50	'To Be Arranged'
Fall	MATH0090	C09	17480	Th	6:40-8:00PM	'To Be Arranged'
Fall	MATH0090	C10	17481	Th	6:40-8:00PM	'To Be Arranged'
Spr	MATH0090	S01	20113	MWF	11:00-11:50(04)	(D. Katz)
Spr	MATH0090	S02	20114	TTh	9:00-10:20(05)	'To Be Arranged'
Spr	MATH0090	C01	25847	T	10:30-11:50	'To Be Arranged'
Spr	MATH0090	C02	25848	T	1:00-2:20	'To Be Arranged'
Spr	MATH0090	C03	25849	T	2:30-3:50	'To Be Arranged'
Spr	MATH0090	C04	25850	T	6:40-8:00PM	'To Be Arranged'

MATH 0100. Single Variable Calculus, Part II.
A continuation of the material of MATH 90 including further development of techniques of integration. Other topics covered are infinite series, power series, Taylor's formula, polar coordinates, parametric equations, introduction to differential equations, and numerical methods. MATH 90 and 100 or the equivalent are recommended for all students intending to concentrate in mathematics or the sciences. MATH 100 may not be taken in addition to MATH 170 or MATH 190.

Fall	MATH0100	S01	10145	Arranged		(Y. Hsu)
Fall	MATH0100	C01	17483	T	9:00-10:20	'To Be Arranged'
Fall	MATH0100	C02	17484	T	9:00-10:20	'To Be Arranged'
Fall	MATH0100	C03	17485	T	9:00-10:20	'To Be Arranged'
Fall	MATH0100	C04	17486	T	10:30-11:50	'To Be Arranged'
Fall	MATH0100	C05	17487	T	10:30-11:50	'To Be Arranged'
Fall	MATH0100	C06	17488	T	10:30-11:50	'To Be Arranged'
Fall	MATH0100	C07	17489	T	1:00-2:20	'To Be Arranged'
Fall	MATH0100	C08	17490	T	1:00-2:20	'To Be Arranged'
Fall	MATH0100	C09	17491	T	2:30-3:50	'To Be Arranged'
Fall	MATH0100	C10	17492	T	2:30-3:50	'To Be Arranged'
Fall	MATH0100	C12	17494	T	6:40-8:00PM	'To Be Arranged'
Fall	MATH0100	C13	17495	T	6:40-8:00PM	'To Be Arranged'
Spr	MATH0100	S01	20115	MWF	10:00-10:50(03)	(D. Katz)
Spr	MATH0100	S02	20116	TTh	2:30-3:50(11)	'To Be Arranged'
Spr	MATH0100	S03	20117	MWF	9:00-9:50(02)	'To Be Arranged'
Spr	MATH0100	S04	20118	MWF	12:00-12:50(01)	'To Be Arranged'
Spr	MATH0100	C01	25851	Th	9:00-10:20	'To Be Arranged'
Spr	MATH0100	C02	25852	Th	9:00-10:20	'To Be Arranged'
Spr	MATH0100	C03	25853	Th	10:30-11:50	'To Be Arranged'
Spr	MATH0100	C04	25854	Th	10:30-11:50	'To Be Arranged'
Spr	MATH0100	C05	25855	Th	1:00-2:20	'To Be Arranged'
Spr	MATH0100	C06	25856	Th	1:00-2:20	'To Be Arranged'
Spr	MATH0100	C07	25857	Th	2:30-3:50	'To Be Arranged'
Spr	MATH0100	C08	25858	Th	2:30-3:50	'To Be Arranged'
Spr	MATH0100	C09	25859	Th	6:40-8:00PM	'To Be Arranged'
Spr	MATH0100	C10	25860	Th	6:40-8:00PM	'To Be Arranged'

MATH 0170. Single Variable Calculus, Part II (Accelerated).
This course, which covers roughly the same material and has the same prerequisites as MATH 100, covers integration techniques, sequences and series, parametric and polar curves, and differential equations of first and second order. Topics will generally include more depth and detail than in MATH 100. MATH 170 may not be taken in addition to MATH 100 or MATH 190.

MATH 0180. Multivariable Calculus.
Three-dimensional analytic geometry. Differential and integral calculus of functions of two or three variables: partial derivatives, multiple integrals, Green's Theorem, Stokes' theorem, and the divergence theorem. Prerequisite: MATH 100, MATH 170, or MATH 190, or advanced placement or written permission. [MATH 180 may not be taken in addition to MATH 200 or MATH 350.]

Fall	MATH0180	S01	10146	MWF	11:00-11:50(16)	(C. Daly)
Fall	MATH0180	S02	10147	MWF	12:00-12:50(15)	'To Be Arranged'
Fall	MATH0180	S03	10148	TTh	9:00-10:20(05)	'To Be Arranged'
Fall	MATH0180	C01	17499	T	12:00-12:50	'To Be Arranged'
Fall	MATH0180	C02	17500	T	12:00-12:50	'To Be Arranged'
Fall	MATH0180	C03	17501	T	2:30-3:20	'To Be Arranged'
Fall	MATH0180	C04	17502	T	6:40-7:30	'To Be Arranged'
Spr	MATH0180	S01	20119	TTh	1:00-2:20(08)	'To Be Arranged'
Spr	MATH0180	S02	20120	TTh	10:30-11:50(09)	'To Be Arranged'
Spr	MATH0180	S03	20121	MWF	12:00-12:50(01)	'To Be Arranged'
Spr	MATH0180	C01	25862	T	9:00-9:50	'To Be Arranged'
Spr	MATH0180	C02	25863	T	10:30-11:20	'To Be Arranged'
Spr	MATH0180	C03	25864	T	1:00-1:50	'To Be Arranged'
Spr	MATH0180	C04	25865	T	6:40-8:00PM	'To Be Arranged'

MATH 0190. Single Variable Calculus, Part II (Physics/Engineering).
This course, which covers roughly the same material and has the same prerequisites as MATH 100, is intended for students with a special interest in physics or engineering. The main topics are: applications and techniques of integration; sequences, series, and power series methods; parametric equations and polar coordinates; additional topics at instructor's discretion. MATH 190 may not be taken in addition to MATH 100 or MATH 170.

Fall	MATH0190	S01	10149	MWF	9:00-9:50(09)	(J. Kostiuk)
Fall	MATH0190	S02	10150	MWF	1:00-1:50(08)	(C. Daly)

MATH 0200. Multivariable Calculus (Physics/Engineering).
This course, which covers roughly the same material as MATH 180, is intended for students with a special interest in physics or engineering. The main topics are: geometry of three-dimensional space; partial derivatives; Lagrange multipliers; double, surface, and triple integrals; vector analysis; Stokes' theorem and the divergence theorem, with applications to electrostatics and fluid flow. Prerequisite: MATH 100, MATH 170, or MATH 190, or advanced placement or written permission . [MATH 200 may not be taken in addition to MATH 180 or MATH 350.]

Fall	MATH0200	S01	10151	MWF	2:00-2:50(01)	'To Be Arranged'
Fall	MATH0200	S02	10152	MWF	12:00-12:50(15)	'To Be Arranged'
Fall	MATH0200	S03	10153	TTh	1:00-2:20(06)	(Y. Hsu)
Fall	MATH0200	C01	17508	Th	10:30-11:20	'To Be Arranged'
Fall	MATH0200	C02	17509	Th	12:00-12:50	'To Be Arranged'
Fall	MATH0200	C03	17510	Th	2:30-3:50	'To Be Arranged'
Fall	MATH0200	C04	17511	Th	6:40-7:30	'To Be Arranged'
Fall	MATH0200	C05	17658	Th	9:00-9:50	'To Be Arranged'
Spr	MATH0200	S01	20122	MWF	12:00-12:50(01)	'To Be Arranged'
Spr	MATH0200	S02	20123	TTh	10:30-11:50(09)	(J. Gomez Serrano)
Spr	MATH0200	S03	20124	TTh	2:30-3:50(11)	(J. Gomez Serrano)
Spr	MATH0200	C01	25866	T	9:00-9:50	'To Be Arranged'
Spr	MATH0200	C02	25867	T	12:00-12:50	'To Be Arranged'
Spr	MATH0200	C03	25868	T	12:00-12:50	'To Be Arranged'
Spr	MATH0200	C04	25869	T	6:40-7:30	'To Be Arranged'
Spr	MATH0200	C05	25894	T	2:30-3:20	'To Be Arranged'

MATH 0350. Multivariable Calculus With Theory.
This course provides a rigorous treatment of multivariable calculus. Topics covered include vector analysis, partial differentiation, multiple integration, line integrals, Green's theorem, Stokes' theorem, and the divergence theorem. MATH 0350 covers the same material as MATH 0180, but with more emphasis on theory and on understanding proofs. Prerequisites: MATH 0100, MATH 0170, or MATH 0190, or advanced placement or written permission. [MATH 0350 may not be taken in addition to MATH 0180 or MATH 0200.]

Fall	MATH0350	S01	10154	MWF	1:00-1:50(08)	(B. Dees)

MATH 0420. Introduction to Number Theory.
An overview of one of the most beautiful areas of mathematics. Ideal for any student who wants a taste of mathematics outside of, or in addition to, the calculus sequence. Topics include: prime numbers, congruences, quadratic reciprocity, sums of squares, Diophantine equations, and, as time permits, such topics as cryptography and continued fractions. No prerequisites.

Spr	MATH0420	S01	20125	MWF	2:00-2:50(07)	(Z. Wei)

MATH 0520. Linear Algebra.
A first course in linear algebra designed to develop students' problem solving skills, mathematical writing skills, and gain facility with the applications and theory of linear algebra. Topics will include: vector spaces, linear transformations, matrices, systems of linear equations, bases, eigenvalues, and additional topics at instructor's discretion. Applications may include differential equations, difference equations, least squares approximations, and models in economics and in biological and physical sciences. MATH 0520 or MATH 0540 is a prerequisite for all 1000-level courses in Mathematics except MATH 1260 or MATH 1610. Recommended prerequisite: MATH 0100 or equivalent. May not be taken in addition to MATH 0540.

Fall	MATH0520	S01	10155	MWF	11:00-11:50(16)	(Z. Wei)
Fall	MATH0520	S02	10156	MWF	10:00-10:50(14)	(J. Kostiuk)
Fall	MATH0520	S03	10157	MWF	12:00-12:50(15)	(J. Kostiuk)
Fall	MATH0520	S04	10158	TTh	9:00-10:20(05)	(J. Kostiuk)
Fall	MATH0520	S05	10159	TTh	10:30-11:50(13)	(J. Kostiuk)
Fall	MATH0520	S06	17334	TTh	1:00-2:20(06)	(N. Wagner)
Fall	MATH0520	S07	17335	TTh	2:30-3:50(12)	'To Be Arranged'
Spr	MATH0520	S01	20126	MWF	9:00-9:50(02)	'To Be Arranged'
Spr	MATH0520	S02	20127	MWF	10:00-10:50(03)	(J. Kostiuk)
Spr	MATH0520	S03	20128	MWF	12:00-12:50(01)	'To Be Arranged'
Spr	MATH0520	S04	20129	MWF	1:00-1:50(06)	(B. Dees)
Spr	MATH0520	S05	20130	MWF	2:00-2:50(07)	'To Be Arranged'
Spr	MATH0520	S06	20131	TTh	9:00-10:20(05)	'To Be Arranged'
Spr	MATH0520	S07	20132	TTh	10:30-11:50(09)	'To Be Arranged'

MATH 0540. Linear Algebra With Theory.
This course provides a rigorous introduction to the theory of linear algebra. Topics covered include: matrices, linear equations, determinants, and eigenvalues; vector spaces and linear transformations; inner products; Hermitian, orthogonal, and unitary matrices; and Jordan normal form. MATH 540 provides a more theoretical treatment of the topics in MATH 520, and students will have opportunities during the course to develop proof-writing skills. Recommended prerequisite: MATH 100, MATH 170, or MATH 190. [MATH 540 may not be taken in addition to MATH 520.]

Fall	MATH0540	S01	10160	MWF	9:00-9:50(09)	(P. Zenz)
Fall	MATH0540	S02	17336	TTh	2:30-3:50(12)	(S. Hashimoto)
Spr	MATH0540	S01	20133	MWF	10:00-10:50(03)	(I. Vogt)

MATH 0550. Problems from the History of Mathematics.
This course presents a history of mathematics through the lens of famous mathematical problems. Beginning in Ancient Greece and Babylon and continuing to the present, we discuss the problems that shaped the development of modern mathematics. Sample topics include the impossible constructions of Ancient Greece, paradoxes from the birth of calculus, the problems that gave rise to graph theory, and the rise of computer-assisted proofs.

MATH 0580. Mathematical Forms in Architecture.
This project will explore and advance innovative applications of mathematics to architecture using computational methods. Historically, architecture has been guided primarily by an intuitive creative process. In contrast to the end-results of intuitive design, many "optimal" forms--i.e. geometric shapes and configurations that satisfy extremal conditions--are unique because they are the result of systematic physical experiments or explicit mathematical study in addition to imaginative imput. Classic questions for which human intuition alone has been incapable of finding a solution include: What is the exact shape of the optimal arch?, or What is the shape of a child's slide that minimizes the time of travel? The use of computational methods to generate solutions to these problems will be made considerably simpler via optimization libraries in Mathematica. The application to architecture in this project will provide students a unique concrete backdrop to visualize solutions to these problems.

MATH 0750. Introduction to Higher Mathematics.
This semester-long class will expose students to several fundamental areas of mathematics. It will be team taught by three members of the faculty. Topics, which will vary from year to year, will be chosen from logic and set theory, number theory, abstract algebra, combinatorics and graph theory, analysis, and geometry. Approximately 4 weeks will be devoted to each of the selected topics.

Fall	MATH0750	S01	10161	TTh	2:30-3:50(12)	(J. Pipher)

MATH 0760. Introduction to Higher Mathematics.
This year-long class will expose students to six fundamental areas of mathematics. It will be team taught by six members of the faculty. Fall topics will include logic, combinatorics, and analysis. Spring topics will include number theory, algebra, and geometry. Approximately 4 weeks will be devoted to each topic.

MATH 1000. The Art of Writing Mathematics.
Math 1001 is an introduction to proof-writing designed to prepare students for further exploration of rigorous mathematics. Students will be trained to identify and employ a variety of proof-techniques such as direct proof, proof by contradiction, proof by induction, and proof by cases, to name a few. Mathematical topics covered include samplings of set theory, logic, and number theory, with additional topics chosen at the instructors discretion if time permits. Recommended Prerequisites: MATH 0520, MATH 0540, MATH 0100, MATH 0190, MATH 0180, MATH 0200, or MATH 0350. Students with little proof writing experience are encouraged to take MATH 1001 prior to taking, or concurrently with, other 1000-level Mathematics courses.

Spr	MATH1000	S01	26198	MWF	11:00-11:50(04)	(J. Kostiuk)

MATH 1001. The Art of Writing Mathematics.
Math 1001 is an introduction to proof-writing designed to prepare students for further exploration of rigorous mathematics. Students will be trained to identify and employ a variety of proof-techniques such as direct proof, proof by contradiction, proof by induction, and proof by cases, to name a few. Mathematical topics covered include samplings of set theory, logic, and number theory, with additional topics chosen at the instructors discretion if time permits. Recommended Prerequisites: MATH 0520, MATH 0540, MATH 0100, MATH 0190, MATH 0180, MATH 0200, or MATH 0350.
Students with little proof writing experience are encouraged to take MATH 1001 prior to taking, or concurrently with, other 1000-level Mathematics courses.

MATH 1010. Analysis: Functions of One Variable.
Completeness properties of the real number system, topology of the real line. Proof of basic theorems in calculus, infinite series. Topics selected from ordinary differential equations. Fourier series, Gamma functions, and the topology of Euclidean plane and 3-space. Prerequisite: MATH 0180, 0200, or 0350. MATH 0520 or 0540 may be taken concurrently. Most students are advised to take MATH 1010 before MATH 1130.

Spr	MATH1010	S01	25774	MWF	11:00-11:50(04)	(B. Dees)

MATH 1030. Graph Theory.
This course covers important material about graph theory, such as spanning trees, network flow problems, matching problems, coloring problems, planarity, Cayley graphs, spectral theory on graphs, and Ramsey Theory. The emphasis will be on a combination of theory and algorithms. Depending on the instructor, connections to such fields as combinatorics, geometry, or computer science might be emphasized. Prerequisite: MATH 0180, 0200 or 0350 and MATH 0520 or 0540 are recommended.

Spr	MATH1030	S01	26199	TTh	1:00-2:20(08)	(J. Jung)

MATH 1040. Fundamental Problems of Geometry.
This class discusses geometry from a modern perspective. Topics include hyperbolic, projective, conformal, and affine geometry, and various theorems and structures built out of them. Prerequisite: MA 0520, MA 0540, or permission of the instructor.

Spr	MATH1040	S01	20135	TTh	2:30-3:50(11)	(J. Kahn)

MATH 1060. Differential Geometry.
The study of curves and surfaces in 2- and 3-dimensional Euclidean space using the techniques of differential and integral calculus and linear algebra. Topics include curvature and torsion of curves, Frenet-Serret frames, global properties of closed curves, intrinsic and extrinsic properties of surfaces, Gaussian curvature and mean curvature, geodesics, minimal surfaces, and the Gauss-Bonnet theorem.

Fall	MATH1060	S01	10162	MWF	10:00-10:50(14)	(C. Breiner)

MATH 1080. Cryptography.
This course focuses on the mathematics underlying public key cryptosystems, digital signatures, and other topics in cryptography. A sampling of mathematical topics, such as groups, rings, fields, number theory, probability, complexity theory, elliptic curves, and lattices, will be introduced and applied to cryptography. No prior knowledge of these topics is assumed, nor is prior programming experience needed; any programming knowledge required will be covered in class.

Spr	MATH1080	S01	26200	MWF	9:00-9:50(02)	(P. Zenz)

MATH 1110. Ordinary Differential Equations.
Ordinary differential equations, including existence and uniqueness theorems and the theory of linear systems. Topics may also include stability theory, the study of singularities, and boundary value problems.

Fall	MATH1110	S01	10163	MWF	11:00-11:50(16)	(B. Vergara Biggio)

MATH 1120. Partial Differential Equations.
The wave equation, the heat equation, Laplace's equation, and other classical equations of mathematical physics and their generalizations, discussion of well-posedness problems. The method of characteristics, initial and boundary conditions, separation of variables, solutions in series of eigenfunctions, Fourier series, maximum principles, Green’s identities and Green’s functions.

Spr	MATH1120	S01	20136	MWF	2:00-2:50(07)	'To Be Arranged'

MATH 1130. Functions of Several Variables.
A course on calculus on manifolds. Included are differential forms, integration, and Stokes' formula on manifolds, with applications to geometrical and physical problems, the topology of Euclidean spaces, compactness, connectivity, convexity, differentiability, and Lebesgue integration. It is recommended that a student take a 1000-level course in analysis (MATH 1010 or MATH 1260) before attempting MATH 1130.

MATH 1140. Functions Of Several Variables.
See Functions Of Several Variables (MATH 1130) for course description. Prerequisite: MATH 1130 or instructor permission.

MATH 1150. Machine Learning for Scientific Modeling: Data-Driven Discovery of Differential Equations.
This junior/senior level course will explore the use of Machine Learning to automate the discovery and calibration of models involving differential equations directly from data. After introducing the basic machine learning tools (Gaussian Processes and Neural Networks) we will see how they can be combined with ODE and PDE computational methods to generate models in physics, medicine, and finance. The course will progress to a survey of recent research works on the topic. No prior knowledge of machine learning is required.

MATH 1210. Probability.
Basic probability theory including random variables, distribution functions, independence, expectation, variance, and conditional expectation. Classical examples of probability density and mass functions (binomial, geometric, normal, exponential) and their applications. Stochastic processes including discrete and continuous time Poisson processes, Markov chains, and Brownian motion.

Fall	MATH1210	S01	17664	MWF	2:00-2:50(01)	(B. Vergara Biggio)

MATH 1230. Graph Theory.
This course covers important material about graph theory, such as spanning trees, network flow problems, matching problems, coloring problems, planarity, Cayley graphs, spectral theory on graphs, and Ramsey Theory. The emphasis will be on a combination of theory and algorithms. Depending on the instructor, connections to such fields as combinatorics, geometry, or computer science might be emphasized. Prerequisite: MATH 0180, 0200 or 0350 and MATH 0520 or 0540 are recommended.

MATH 1260. Complex Analysis.
Examines one of the cornerstones of mathematics. Complex differentiability, Cauchy-Riemann differential equations, contour integration, residue calculus, harmonic functions, geometric properties of complex mappings. Prerequisite: MATH 0180, 0200, or 0350. This course does not require MATH 0520 or 0540.

MATH 1270. Topics in Functional Analysis.
Infinite-dimensional vector spaces with applications to some or all of the following topics: Fourier series and integrals, distributions, differential equations, integral equations, calculus of variations. Prerequisite: At least one 1000-level course in Mathematics or Applied Mathematics, or permission of the instructor.

Spr	MATH1270	S01	25891	TTh	9:00-10:20(05)	'To Be Arranged'

MATH 1410. Topology.
Topology of Euclidean spaces, winding number and applications, knot theory, fundamental group and covering spaces. Euler characteristic, simplicial complexes, classification of two-dimensional manifolds, vector fields, the Poincaré-Hopf theorem, and introduction to three-dimensional topology. Prerequisites: MATH 0520 or MATH 0540, or instructor permission.

MATH 1460. Complex Analysis.
Examines one of the cornerstones of mathematics. Complex differentiability, Cauchy-Riemann differential equations, contour integration, residue calculus, harmonic functions, geometric properties of complex mappings. Prerequisite: MATH 0180, 0200, or 0350. This course does not require MATH 0520 or 0540.

Fall	MATH1460	S01	17663	MWF	2:00-2:50(01)	'To Be Arranged'

MATH 1530. Abstract Algebra.
A proof-based course that introduces the principles and concepts of modern abstract algebra. Topics will include groups, rings, and fields, with applications to number theory, the theory of equations, and geometry. Previous proof-writing experience is not required. MATH 1530 is required of all students concentrating in mathematics. It is strongly suggested that potential mathematics concentrators make MATH 1530 one of the first thousand level mathematics classes that they take.

Fall	MATH1530	S01	10167	TTh	10:30-11:50(13)	(S. Hashimoto)
Fall	MATH1530	S02	17337	TTh	1:00-2:20(06)	(J. Jung)
Spr	MATH1530	S01	20139	MWF	1:00-1:50(06)	(S. Hashimoto)

MATH 1540. Topics in Abstract Algebra.
Galois theory together with selected topics in algebra. Examples of subjects which have been presented in the past include algebraic curves, group representations, and the advanced theory of equations. Prerequisite: MATH 1530.

Fall	MATH1540	S01	17338	TTh	10:30-11:50(13)	(J. Silverman)

MATH 1560. Number Theory.
Selected topics in number theory will be investigated. Unique factorization, prime numbers, modular arithmetic, arithmetic functions, quadratic reciprocity, finite fields, and related topics. Prerequisite: MATH 1530 or written permission.

Fall	MATH1560	S01	10168	MWF	9:00-9:50(09)	(Z. Wei)

MATH 1580. Cryptography.
This course focuses on the mathematics underlying public key cryptosystems, digital signatures, and other topics in cryptography. A sampling of mathematical topics, such as groups, rings, fields, number theory, probability, complexity theory, elliptic curves, and lattices, will be introduced and applied to cryptography. No prior knowledge of these topics is assumed, nor is prior programming experience needed; any programming knowledge required will be covered in class.

MATH 1610. Probability.
Basic probability theory including random variables, distribution functions, independence, expectation, variance, and conditional expectation. Classical examples of probability density and mass functions (binomial, geometric, normal, exponential) and their applications. Stochastic processes including discrete and continuous time Poisson processes, Markov chains, and Brownian motion.

MATH 1620. Mathematical Statistics.
Frequentist and Bayesian viewpoints and decision theory principles. Concepts from probability, including the central limit theorem and multivariate normal distributions, and asymptotic estimates. Inferences from independent, identically distributed sampling: point estimation, confidence intervals, and hypothesis testing. Analysis of variance (ANOVA) and generalized linear models of regression.

MATH 1630. Real Analysis I.
A rigorous introduction to real analysis, this course treats topics in point set topology, function spaces, differentiability of functions on Euclidean spaces, and Fourier series. Among the many topics and theorems we investigate in detail will be connectedness and compactness, the Arzela-Ascoli theorem, the inverse and implicit function theorems, and L^2 and pointwise convergence of Fourier series. It is recommended that a student take MATH 1010 before attempting MATH 1130.

Fall	MATH1630	S01	17662	MWF	1:00-1:50(08)	(J. Holmer)

MATH 1640. Real Analysis II.
A second course in real analysis, in this class we study measure theory and integration as well as Hilbert spaces. Among the many topics we study will be abstract measure and integration theory, Fourier transform, linear functionals and the Riesz representation theorem, compact operators, and the spectral theorem. The course may also include additional material of interest to the students and instructor.

Spr	MATH1640	S01	26120	TTh	10:30-11:50(09)	(N. Kapouleas)

MATH 1710. Topology.
Topology of Euclidean spaces, winding number and applications, knot theory, fundamental group and covering spaces. Euler characteristic, simplicial complexes, classification of two-dimensional manifolds, vector fields, the Poincaré-Hopf theorem, and introduction to three-dimensional topology. Prerequisites: MATH 0520 or MATH 0540, or instructor permission.

Spr	MATH1710	S01	26206	TTh	1:00-2:20(08)	(C. Daly)

MATH 1810A. Applied Algebraic Topology.
Topology is a powerful tool for identifying, describing, and characterizing the essential features of functions and spaces. In the recent years some of these methods have been adapted to study the shape of data collected from a range of different fields, including graphics and visualization, computational biology, etc. This course is an introduction to the basic concepts and topological structures behind these developments, focusing on persistent homology and mapper. Projects will involve using these methods to analyze and describe the shape of concrete data sets.

MATH 1810B. A Second Course in Linear Algebra.
This is a course in linear algebra for students who have had a standard first course (vector space, linear map, characteristic polynomial). We'll emphasize coordinate-free constructions and universal properties as much as possible. Among the topics we'll study are sum, product and quotient spaces; duality (kernel, cokernel); tensor product (Hilbert's third problem, differential form); homological algebra (exact sequence, snake lemma); normal forms (Frobenius, Weyr, Smith) and invariant factors. If there are sufficient time and interest, we might explore other topics, such as geometric algebra, control theory (pole placement) and/or tropical linear algebra.

MATH 1820A. Introduction to Lie Algebras.
Lie groups and Lie algebras are important, because they are the symmetries of structures such as quadratic forms, differential systems and smooth manifolds. The prototype of a Lie algebra is the space of 3-vectors together with their cross product, which is closely related to the Lie group of rotations. We will see how this basic example generalizes, mostly in the context of matrices. We'll examine special types of Lie algebras, such as nilpotent, solvable and semi-simple, study root systems and their diagrams, explore some representation theory, and end with the classification of the simple Lie algebras. Prerequisite: MATH 1530.

MATH 1970. Honors Conference.
Collateral reading, individual conferences. Section numbers vary by instructor. Please check Banner for the correct section number and CRN to use when registering for this course.

MATH 2010. Differential Geometry.
Introduction to differential geometry (differentiable manifolds, differential forms, tensor fields, homogeneous spaces, fiber bundles, connections, and Riemannian geometry), followed by selected topics in the field. Pre-reqs: MATH 2110 and undergraduates require permission from the instructor.

Spr	MATH2010	S01	20143	TTh	2:30-3:50(11)	(N. Kapouleas)

MATH 2050. Algebraic Geometry.
Complex manifolds and algebraic varieties, sheaves and cohomology, vector bundles, Hodge theory, Kähler manifolds, vanishing theorems, the Kodaira embedding theorem, the Riemann-Roch theorem, and introduction to deformation theory. Pre-reqs: MATH 2510 and MATH 2520 and undergraduates require permission from the instructor.

Spr	MATH2050	S01	25776	MWF	1:00-1:50(06)	(E. Larson)

MATH 2060. Algebraic Geometry.
See Algebraic Geometry (MATH 2050) for course description.

MATH 2110. Introduction to Manifolds.
Inverse Function Theorem, manifolds and submanifolds, tangent and cotangent bundles, transversality, flows and vector fields, Frobenius Theorem, vector bundles, tensors and differential forms, Sard's Theorem, introduction to Lie groups. Pre-reqs: MATH 1060, MATH 1140 and preferably MATH 1410 and undergraduates require permission from the instructor.

Fall	MATH2110	S01	10171	TTh	2:30-3:50(12)	(J. Kahn)

MATH 2210. Real Function Theory.
Real numbers, outer measures, measures, Lebesgue measure, integrals of measurable functions, Holder and Minkowski inequalities, modes of onvergence, L^p spaces, product measures, Fubini's Theorem, signed measures, Radon-Nikodym theorem, dual space of L^p and of C, Hausdorff measure.

MATH 2220. Real Function Theory.
The basics of Hilbert space theory, including orthogonal projections, the Riesz representation theorem, and compact operators. The basics of Banach space theory, including the open mapping theorem, closed graph theorem, uniform boundedness principle, Hahn-Banach theorem, Riesz representation theorem (pertaining to the dual of C_0(X)), weak and weak-star topologies. Various additional topics, possibly including Fourier series, Fourier transform, ergodic theorems, distribution theory, and the spectral theory of linear operators.

MATH 2250. Complex Function Theory.
Introduction to the theory of analytic functions of one complex variable. Content varies somewhat from year to year, but always includes the study of power series, complex line integrals, analytic continuation, conformal mapping, and an introduction to Riemann surfaces.

Fall	MATH2250	S01	10182	MWF	11:00-11:50(16)	(S. Treil)

MATH 2260. Complex Function Theory.
See Complex Function Theory (MATH 2250) for course description.

Spr	MATH2260	S01	20146	MWF	1:00-1:50(06)	(S. Treil)

MATH 2370. Partial Differential Equations.
The theory of the classical partial differential equations; the method of characteristics and general first order theory. The Fourier transform, the theory of distributions, Sobolev spaces, and techniques of harmonic and functional analysis. More general linear and nonlinear elliptic, hyperbolic, and parabolic equations and properties of their solutions, with examples drawn from physics, differential geometry, and the applied sciences. Semester II concentrates on special topics chosen by the instructor.

Fall	MATH2370	S02	10179	MWF	1:00-1:50(08)	(B. Pausader)

MATH 2380. Partial Differential Equations.
The theory of the classical partial differential equations; the method of characteristics and general first order theory. The Fourier transform, the theory of distributions, Sobolev spaces, and techniques of harmonic and functional analysis. More general linear and nonlinear elliptic, hyperbolic, and parabolic equations and properties of their solutions, with examples drawn from physics, differential geometry, and the applied sciences. Semester II of this course concentrates on special topics chosen by the instructor.

Spr	MATH2380	S01	20151	MWF	2:00-2:50(07)	(J. Holmer)

MATH 2410. Topology.
An introduction to algebraic topology. Topics include fundamental group, covering spaces, simplicial and singular homology, CW complexes, and an introduction to cohomology. Pre-reqs: MATH 1410, MATH 1530, and MATH 1010 and/or MATH 1130 and undergraduates require permission from the instructor.

Fall	MATH2410	S01	10174	TTh	1:00-2:20(06)	(T. Goodwillie)

MATH 2420. Algebraic Topology.
This is a continuation of MATH 2410. Topics include cohomology, cup products, Poincare duality, and other topics chosen by the instructor.

Spr	MATH2420	S01	20147	TTh	9:00-10:20(05)	(B. Tshishiku)

MATH 2450. Exchange Scholar Program.

Fall	MATH2450	S01	16594	Arranged		'To Be Arranged'

MATH 2510. Algebra.
Basic properties of groups, rings, fields, and modules. Topics include: finite groups, representations of groups, rings with minimum condition, Galois theory, local rings, algebraic number theory, classical ideal theory, basic homological algebra, and elementary algebraic geometry. Pre-reqs: MATH 1530 and MATH 1540 and undergraduates require permission from the instructor.

Fall	MATH2510	S01	10175	MWF	10:00-10:50(14)	(M. Chan)

MATH 2520. Algebra.
See Algebra (MATH 2510) for course description. Pre-reqs: MATH 2510 and undergraduates require permission from the instructor.

Spr	MATH2520	S01	20148	MWF	10:00-10:50(03)	(M. Chan)

MATH 2530. Number Theory.
Introduction to algebraic and analytic number theory. Topics covered during the first semester include number fields, rings of integers, primes and ramification theory, completions, adeles and ideles, and zeta functions. Content of the second semester varies from year to year; possible topics include class field theory, arithmetic geometry, analytic number theory, and arithmetic K-theory. Pre-reqs: MATH 2510 and undergraduates require permission from the instructor.

Fall	MATH2530	S01	10176	TTh	10:30-11:50(13)	(I. Vogt)

MATH 2540. Number Theory.
See Number Theory (MATH 2530) for course description.

Spr	MATH2540	S01	20149	MWF	11:00-11:50(04)	(J. Silverman)

MATH 2630. Probability.
Introduces probability spaces, random variables, expectation values, and conditional expectations. Develops the basic tools of probability theory, such fundamental results as the weak and strong laws of large numbers, and the central limit theorem. Continues with a study of stochastic processes, such as Markov chains, branching processes, martingales, Brownian motion, and stochastic integrals. Students without a previous course in measure theory should take MATH 2210 (or APMA 2110) concurrently.

MATH 2640. Probability.
See MATH 2630 for course description.

MATH 2710A. Probability, Quantum Field Theory, and Geometry.

MATH 2710B. Solitary Waves.

MATH 2710C. Gluing Constructions in Differential Geometry.

MATH 2710D. Lie Groups and Lie Algebras.

MATH 2710E. Arithmetic Groups.

MATH 2710F. Stable Homotopy Theory.
No description available.

MATH 2710H. Topics in Complex and p-adic Dynamics.
No description available.

MATH 2710I. Topics in Effective Harmonic Analysis.
Graduate topics course in Harmonic Analysis.

MATH 2710P. Harmonic Analysis on Polytopes and Cones.
Graduate Topics course in harmonic analysis.

MATH 2710R. Problems of the Uncertainty Principle in Harmonic Analysis.
Graduate Topics course in Harmonic Analysis.

MATH 2710T. Random Walks, Spanning Trees, and Abelian Sandpiles.
This is an advanced level discussion seminar for specific topics in probability. We will study random walks on networks, the uniform spanning tree model, and the abelian sandpile model of self-organized criticality, and their connections to one another. Using these connections, we will derive properties of these objects on large graphs. We will also cover related topics such as the random walk loop soup.

MATH 2720A. Topics in Harmonic Analysis.

MATH 2720B. Multiple Dirichlet Series.

MATH 2720C. Curves on Surfaces and the Classification of Finitely Generated Kleinian Groups.
This is a course in the study of geometry and topology of hyperbolic 3-manifolds.

MATH 2720D. Piecewise Isometric Maps.
This class will cover a variety of topics, all more or less related to dynamical systems that are defined by piecewise isometric maps. Topics may include:polygonal billiards and flat cone surfaces; outer billiards; interval exchange maps; The Gauss map and continued fractions; aperiodic tilings, such as the Penrose tiling; cut and paste theorems about polyhedra; and Ashwin's conjecture about piecewise rotation maps. A fairly large part of the class will be devoted to the explanation of the instructor's proof of the Moser-Neumann conjecture for outer billiards. For this part, the instructor will use his book on the subject. For other parts of the course, a variety of sources will be used.

MATH 2720E. Advanced Topics in Mathematics.

Fall	MATH2720E	S01	10177	MWF	2:00-2:50(01)	(E. Larson)
Spr	MATH2720E	S01	20150	TTh	1:00-2:20(08)	(T. Goodwillie)

MATH 2720F. Topics in Geometric Analysis.
No description available.

MATH 2720G. Introduction to Hodge Structures.
No description available.

MATH 2720H. Discrete Groups, Ergodic Theory and Hyperbolic Geometry.
No description available.

MATH 2720I. Automorphic Representations for GL(2).
Graduate topics course in automorphic representations for GL(2).

MATH 2720N. Groups Acting on Trees.
This course will be an introduction to geometric group theory from the viewpoint of groups acting on trees. Some topics that may be covered included Bass-Serre theory, R-trees and the Rips machine and groups acting on quasi-trees.

MATH 2720O. Equivariant Homotopy Theory.
This course will serve as an introduction to equivariant homotopy theory, with an emphasis on intuition and with a grounding in concrete computations. We will begin with the homotopy theory of equivariant spaces, seeing what can be said here that mirrors the non-equivariant cases, before introducing stabilization and discussing the kinds of problems stabilization works to solve. Here, we have lots of choices for how we stabilize, and we will spend a little time discussing this and the consequences. Having developed the foundations, the end of the course will focus on student-led presentations on applications of equivariant homotopy theory.

MATH 2720P. Stability Problems in Non-collisional Kinetic Theory.
We will cover the local and global well-posedness for solutions to the Vlasov-Poisson problem, consider steady solution and move on to their stability, starting with the stability of vacuum, we will move on to homogeneous equilibrium and the connection to Landau

MATH 2970. Preliminary Exam Preparation.
No description available.

Fall	MATH2970	S01	16595	Arranged	'To Be Arranged'
Spr	MATH2970	S01	25254	Arranged	'To Be Arranged'

MATH 2980. Reading and Research.
Independent research or course of study under the direction of a member of the faculty, which may include research for and preparation of a thesis. Section numbers vary by instructor. Please check Banner for the correct section number and CRN to use when registering for this course.

MATH 2990. Thesis Preparation.
For graduate students who have met the residency requirement and are continuing research on a full time basis.

Fall	MATH2990	S01	16596	Arranged	'To Be Arranged'
Spr	MATH2990	S01	25255	Arranged	'To Be Arranged'

MATH XLIST. Courses of Interest to Students Majoring in Mathematics.