

MATHEMATICS (MATH)

Updated February 2013

Note: The department/program code MATH replaces the former codes 32. Students cannot hold credit in MATH-xxxx and the former 32.xxxx having the same course number (e.g., MATH-1101(6) and 32.1101(6)).

Co-Chairs: O.R. Oellermann, T. Visentin; **Professors:** J. Currie, V. Linek, O.R. Oellermann, T. Visentin; **Associate Professors:** J. Babb, A. Stokke, R. Stokke; **Assistant Professor:** S. Gosselin, N. Rampersad; **Instructor:** B. Bector.

DEGREES/PROGRAMS OFFERED

3-Year BA

3-Year BSc

3-Year BSc (Business Stream)

4-Year BA

4-Year BSc

4-Year BSc (Business Stream)

BSc Honours

Minor

INTRODUCTION

Mathematics is the supreme intellectual achievement and the most original creation of the human spirit - Morris Kline.

Mathematics is the Queen and servant of the Sciences - Karl Friedrich Gauss.

Mathematics is just more and more complicated ways of saying 'Pigs is pigs' - Bertrand Russell.

The scope of Mathematics ranges from Computer Science to Philosophy, from Physics to Finance. Mathematics emphasizes precision and logic, but also creativity and problem solving. Students heading for Law or Medicine are well-served by a first degree in Mathematics. Other graduates move into the financial sector or high technology. Some graduates choose to go on to advanced degrees, not only in Mathematics, but also in Statistics, Computer Science, Meteorology or Physics.

The department offers 3-Year and 4-Year BA and BSc degrees, and the Honours BSc. Students pursuing a 3-year or 4-year BSc also have the opportunity to take a Business Stream – a set of core courses in the Faculty of Business that will provide them with the skills needed to enter and succeed in industry and business. See the "Science with a Business Stream" section of this Course Calendar.

The Mathematics department features one of the highest levels of research activity in the University, and offers students a unique glimpse into the ongoing creation of Mathematics.

REQUIREMENTS FOR A 3-YEAR BA/BSc IN MATHEMATICS

ADMISSION REQUIREMENT

Students must consult with the Department Advisor/Honours Advisor in planning their program.

Students who have not obtained a grade of at least C in **MATH-1103(3)** Introduction to Calculus I AND **MATH-1104(3)** Introduction to Calculus II or the equivalent **MATH-1101(6)** Introduction to Calculus are advised not to proceed in a Mathematics major.

GRADUATION REQUIREMENT

90 credit hours

RESIDENCE REQUIREMENT

Degree:

Minimum 30 credit hours.

Major:

Minimum 18 credit hours.

GENERAL DEGREE REQUIREMENT

Humanities:

12 credit hours in Humanities

Writing:

Minimum 3 credit hours of Academic Writing.

Maximum Introductory Courses:

Students may use a maximum of 42 credit hours at the 1000 level. Of these, a maximum of 6 credit hours may be below the 1000 level.

Distribution:

Minimum three (3) credit hours from each of five (5) different subjects.

MAJOR REQUIREMENT

Single Major

Minimum 36 credit hours/Maximum 54 credit hours.

Double Major

Minimum 36 credit hours in Mathematics and specified number of credit hours in the other department/program.

Required courses:

MATH-1103(3) Introduction to Calculus I and **MATH-1104(3)** Introduction to Calculus II or the equivalent **MATH-1101(6)** Introduction to Calculus

MATH-1401(3) Discrete Mathematics

MATH-2105(3) and **MATH-2106(3)** or the former **MATH-2101(6)** Intermediate Calculus

MATH-1201(3) and **MATH-2203(3)** or the former **MATH-2201(6)** Linear Algebra

Minimum six (6) credit hours at the 3000 level.

Combined Major:

Minimum 48 credit hours from two (2) different majors with not less than 18 credit hours from each major subject.

Prescribed courses:

To be determined in consultation with the Department

Students who have not obtained a grade of at least C in **MATH-1103(3)** Introduction to Calculus I and **MATH-1104(3)** Introduction to Calculus II or the equivalent **MATH-1101(6)** Introduction to Calculus are advised not to proceed in a Mathematics major. Students intending to major in Mathematics are strongly advised to take **MATH-1401(3)** Discrete Mathematics in their first year. It is a prerequisite for most second and third year courses in Mathematics. Students majoring in Mathematics are strongly advised to take both **MATH-2105(3)** Intermediate Calculus I and **MATH-2106(3)** Intermediate Calculus II and **MATH-2203(3)** Linear Algebra II by the end of their second year, since several third year courses have these as prerequisites.

Students are encouraged to take more than 36 credit hours in Mathematics.

Students planning to go on to graduate studies are advised to consult with the Department before choosing second year courses.

REQUIREMENTS FOR THE 3-YEAR BSc IN MATHEMATICS WITH A BUSINESS STREAM

Students must complete the requirements of the 3-year BSc in Mathematics degree (see previous section) and the set of core courses indicated in the "Science with a Business Stream" section of the Calendar.

REQUIREMENTS FOR THE 4-YEAR BA/BSc IN MATHEMATICS

ADMISSION REQUIREMENT	36 credit hours previously completed towards a BA/BSc in Mathematics. Students must consult with the Department Chair/Honours Advisor in planning their program.
GRADUATION REQUIREMENT	120 credit hours
RESIDENCE REQUIREMENT	Degree: 60 credit hours Major: 30 credit hours
GENERAL DEGREE REQUIREMENT	
Humanities:	12 credit hours in Humanities
Science:	6 credit hours in Science
Social Sciences (BA only):	12 credit hours
Writing:	3 credit hours of Academic Writing.
Maximum Introductory Courses:	Students may use a maximum of 42 credit hours at the 1000 level. Of these, a maximum of 6 credit hours may be below the 1000 level.
Distribution:	Minimum three (3) credit hours from each of five (5) different subjects.
MAJOR REQUIREMENT	
Single:	Minimum 48 credit hours/Maximum 72 credit hours.
Double Major:	Minimum 48 credit hours in each Major as specified by the department/program.
Cognate (BA only):	Minimum 18 credit hours/Maximum 36 credit hours. Consult the Department for acceptable cognate courses. Maximum Major and Cognate Courses: 84 credit hours combined.
Required courses:	
MATH-1103(3)	Introduction to Calculus I and MATH-1104(3) Introduction to Calculus II or the equivalent
MATH-1401(3)	MATH-1101(6) Introduction to Calculus
MATH-2105(3)	Discrete Mathematics
MATH-2106(3)	Intermediate Calculus I or the former MATH-2101(6) Intermediate Calculus
MATH-1201(3)	Intermediate Calculus II or the former MATH-2101 (6) Intermediate Calculus
MATH-2203(3)	Linear Algebra I or the former MATH-2201(6) Linear Algebra
MATH-3101(6)	Linear Algebra II or the former MATH-2201(6) Linear Algebra
MATH-3202(3)	Advanced Calculus & Analysis
MATH-4101(3)	Group Theory
MATH-4202(3)	Complex Analysis
	Rings and Fields

Students who have not obtained a grade of at least C in **MATH-1103(3)** Introduction to Calculus I and **MATH-1104(3)** Introduction to Calculus II or the equivalent **MATH-1101(6)** Introduction to Calculus are advised not to proceed in a Mathematics major. Students intending to major in Mathematics are strongly advised to take **MATH-1401(3)** Discrete Mathematics in their first year. It is a prerequisite for most second and third year courses in Mathematics.

Students majoring in Mathematics are strongly advised to take both **MATH-2105(3)** Intermediate Calculus I and **MATH-2106(3)** Intermediate Calculus II and **MATH-2203(3)** Linear Algebra II by the end of their second year, since several third year courses have these as prerequisites.

Students planning to go on to graduate studies are advised to consult with the Department before choosing second year courses.

Combined Major:	Minimum 60 credit hours from two (2) different majors with not less than 24 credit hours from each major subject.
Prescribed courses:	To be determined in consultation with the Department.

REQUIREMENTS FOR THE 4-YEAR BSc IN MATHEMATICS WITH A BUSINESS STREAM

Students must complete the requirements of the 4-year BSc in Mathematics degree (see previous section) and the set of core courses indicated in the "Science with a Business Stream" section of the Calendar.

REQUIREMENTS FOR AN HONOURS BSc IN MATHEMATICS

ADMISSION REQUIREMENT	60 credit hours previously completed in a BA or BSc of which at least 21 credit hours are in Mathematics. Students must consult with the Department Chair/Honours Advisor in planning their program.
GRADUATION REQUIREMENT Graduation GPA Requirement:	120 credit hours To graduate with a BSc Honours, students must have a minimum GPA of 3.0 in all Honours subject courses which will be calculated on all course attempts and a 2.75 GPA in all Non-Honours courses which will be calculated as for the general degree (i.e., F's are not included and, in the case of repeated courses, only the highest grade will be used).
RESIDENCE REQUIREMENT	Minimum 60 credit hours. Minimum 30 credit hours, including minimum 18 credit hours in upper level courses 3000/4000) of which a minimum of 9 credit hours are at the 4000 level.
GENERAL DEGREE REQUIREMENT Humanities: Writing: Maximum Introductory Courses: Distribution:	12 credit hours Minimum 3 credit hours of Academic Writing. Students may use a maximum of 42 credit hours at the 1000 level. Of these, a maximum of 6 credit hours may be below the 1000 level. Minimum three (3) credit hours from each of five (5) different subjects.
HONOURS SUBJECT REQUIREMENT Single Honours: Required courses:	Minimum 66 credit hours/Maximum 72 credit hours in the Honours subject. Minimum 30 credit hours in upper-level courses (3000/4000) of which a minimum of 12 credit hours must be at the 4000 level not including MATH-4402(3) and not including courses that are cross-listed with Statistics.
MATH-1103(3)	Introduction to Calculus I and MATH-1104(3) Introduction to Calculus II or the equivalent MATH-1101(6) Introduction to Calculus
MATH-1401(3)	Discrete Mathematics
MATH-2105(3)	Intermediate Calculus I or the former MATH 2101(6) Intermediate Calculus
MATH-2106(3)	Intermediate Calculus II or the former MATH 2101(6)
MATH-1201(3)	Linear Algebra I or the former MATH-2201(6) Linear Algebra
MATH-2203(3)	Linear Algebra II or the former MATH-2201(6) Linear Algebra
MATH-3101(6)	Advanced Calculus & Analysis
MATH-3202(3)	Group Theory
MATH-4101(3)	Complex Analysis
MATH-4202(3)	Rings and Fields

Students who have not obtained a grade of at least C in **MATH-1103(3)** Introduction to Calculus I and **MATH-1104(3)** Introduction to Calculus II or the equivalent **MATH-1101(6)** Introduction to Calculus are advised not to proceed in a Mathematics major. Students intending to major in Mathematics are strongly advised to take **MATH-1401(3)** Discrete Mathematics in their first year. It is a prerequisite for most second and third year courses in Mathematics. Students majoring in Mathematics are strongly advised to take both **MATH-2105(3)** Intermediate Calculus I and **MATH-2106(3)** Intermediate Calculus II and **MATH-2203(3)** Linear Algebra II by the end of their second year, since several third year courses have these as prerequisites. Students planning to go on to graduate studies are advised to consult with the Department before choosing second year courses.

REQUIREMENTS FOR A MINOR IN MATHEMATICS

Degree:	Students must complete a 4-year degree program in order to be eligible to hold the Minor.
Minor:	18 credit hours in the Minor subject, with a minimum of 12 credit hours above the 1000-level
Residence Requirement:	Minimum 12 credit hours in the Minor subject
Required courses:	MATH-1103 (3) Introduction to Calculus I and MATH-1104 (3) Introduction to Calculus II or, the equivalent, MATH-1101 (6) Introduction to Calculus. Any 12 credit hours at the 2000 level, or higher, may be chosen from math courses that are not listed in the "Restrictions" section below. Note: Most upper-level math courses require MATH-1201 (3), Linear Algebra I, and/or MATH-1401 (3), Discrete Mathematics, as prerequisites. Students wishing to obtain a minor in mathematics are therefore encouraged to take one or both of these courses early on in their program.
Restrictions:	MATH-2902 (3) Mathematics Prior to 1640, MATH-2903 (3) Mathematics for Early/Middle Years Teachers,

MATH/PHIL 2901 (3) History of Calculus, MATH/PHIL-2305(3) Philosophy and Mathematics may not be used towards the minor requirement for mathematics.
Students cannot declare the same subject as a Major and a Minor.

GENERAL INFORMATION

Prerequisites

Pre-Calculus Mathematics 40S or Applied Mathematics 40S.

Degree Credit for Introductory Courses

Students are reminded that a maximum of 6 credit hours at the 0000-level may be counted towards the degree. Credit towards the degree will not be granted for both **MATH-1201(3)** Linear Algebra I and the former **MATH-2201(6)** Linear Algebra or both **MATH-2203(3)** Linear Algebra II and the former **MATH-2201(6)** Linear Algebra. Credit towards the degree will not be granted for both **MATH-1102(3)** Basic Calculus (Terminal), **MATH-1103(3)** Introduction to Calculus I and **MATH-1104(3)** Introduction to Calculus II or the equivalent **MATH-1101(6)** Introduction to Calculus

COURSE LISTINGS

Courses are listed in numerical sequence: Students are advised to consult WebAdvisor or the appropriate Timetable on the website for courses to be offered during the current term, as certain courses may not be available in each term. Students are advised to ensure that currently listed courses do not duplicate material studied previously under different course numbers.

MATH-0041(0)	Mathematics Access I	MATH-3202(3)	Group Theory
MATH-0042(0)	Mathematics Access II	MATH-3203(3)	Linear Algebra III
MATH-1101(6)	Introduction to Calculus	MATH-3401(3)	Graph Theory
MATH-1102(3)	Basic Calculus (Terminal)	MATH-3402(3)	Combinatorics
MATH-1103(3)	Introduction to Calculus I	MATH-3403(3)	Mathematical Logic
MATH-1104(3)	Introduction to Calculus II	MATH/STAT-3412(3)	Introduction to Operations Research
MATH-1201(3)	Linear Algebra I	MATH/STAT-3611(3)	Mathematical Statistics I
MATH-1401(3)	Discrete Mathematics	MATH/STAT-3612(3)	Mathematical Statistics II
MATH-2102(3)	Differential Equations I	MATH-3701(3)	Numerical Methods
MATH-2103(3)	Differential Equations II	MATH-3703(6)	Mathematical Modelling
MATH-2105(3)	Intermediate Calculus I	MATH-4001(6)	Directed Readings in Mathematics
MATH-2106(3)	Intermediate Calculus II	MATH-4003(3)	Topics in Mathematics
MATH-2202(3)	Applied Algebra	MATH-4004(3)	Directed Readings in Mathematics
MATH-2203(3)	Linear Algebra II	MATH-4101(3)	Complex Analysis
MATH/PHIL-2305(3)	Philosophy and Mathematics	MATH-4202(3)	Rings and Fields
MATH-2501(3)	Introduction to Number Theory	MATH-4401(3)	Advanced Graph Theory and Combinatorial Optimization
MATH-2701(3)	Linear Optimization	MATH-4402(3)	Networks and Their Applications
MATH-2803(3)	Scientific Computing For Mathematics	MATH-4403(3)	Set Theory
MATH/PHIL-2901(3)	History of Calculus	MATH-4601(3)	Introduction to Topology and Analysis
MATH-2902(3)	Mathematics Prior to 1640	MATH-4602(3)	Real Analysis
MATH-2903(3)	Mathematics for Early/Middle Years Teachers	MATH-4603(3)	Topology
MATH-3101(6)	Advanced Calculus and Analysis		
MATH-3103(3)	Methods in Advanced Calculus		

COURSE DESCRIPTIONS

MATH-0041(0) Mathematics Access I (Le3, La4.5) This course covers mathematics from school math courses.

Topics include the real number system, integer and fraction arithmetic, exponents and radicals, polynomial arithmetic and algebraic expressions, rational expressions, equation solving techniques, coordinate geometry, lines, functions, and geometry of right-angled triangles. This course can be used in lieu of an Applied Math 40S prerequisite for MATH-2903 only. It cannot be used in lieu of an Applied Math 40S prerequisite for any other course. This course may be audited by students who have passed Applied Math 40S, Pre-Calculus 30S or Pre-Calculus 40S. Note: This is a non-credit course offered over 12 weeks.

PREREQUISITE: Grade 10 Pre-Calculus 20S, Grade 11 Pre-Calculus 30S, or Grade 11 Applied Mathematics or permission of department.

RESTRICTIONS: Students who are registered in high school may not register in this course.

MATH-0042(0) Mathematics Access II (Le3, La4.5) This course covers mathematics from high school pre-calculus courses. Topics include the binomial theorem, fractional equations, factorization of polynomials, the Fundamental Theorem of Algebra, synthetic division, complex numbers, inequalities, relations and functions, exponential and logarithmic functions, circular functions, trigonometry and sequences and series. This course can be used in lieu of Pre-Calculus 40S Mathematics for all university prerequisites. This course may be audited by students who have passed Pre-Calculus 40S. Note: This is a non-credit course offered over 12 weeks.

PREREQUISITES: A minimum grade of 65% in Pre-Calculus 30S or MATH-0041 or permission of the department.

RESTRICTIONS: Students who are registered in high school may not register in this course.

MATH-1101(6) INTRODUCTION TO CALCULUS (Le3, La2)

This course covers calculus of a function of one variable. Topics covered include limits, continuity, differentiation and integration of elementary functions (algebraic, exponential, logarithmic, trigonometric and inverse trigonometric), indeterminate forms and l'Hospital's Rule, and improper integrals. Applications covered include maximization and minimization problems, related rates, curve sketching, area, volume, and arc length. A grade of at least C in this course is required to take MATH-2105(3). The material covered in this course is equivalent to the combined material from MATH-1103(3) Introduction to Calculus I and MATH-1104(3) Introduction to Calculus II.

PREREQUISITES: Pre-Calculus Mathematics 40S, MATH-0042 or the former MATH-0040 or permission of the instructor or Department Chair.

NOTE: A grade of at least C in this course is required to take MATH-2105(3).

RESTRICTIONS: A student may not receive credit for MATH-1101 (6), and any of the following: MATH-1102 (3), MATH-1103(3) or MATH-1104(3).

NOTE: Students who have not obtained a minimum grade of 60% in Pre-Calculus 40S are strongly advised to take MATH-0042 Mathematics Access II prior to registering in MATH-1101(6).

MATH-1102(3) BASIC CALCULUS (TERMINAL) (Le3, La2)

This course covers a portion of the calculus of a function of one variable. Topics covered include: limits, continuity, differentiation and integration of elementary functions (algebraic, exponential, and logarithmic). Applications covered include: maximizing and minimizing problems, curve sketching, and area.

PREREQUISITES: Pre-Calculus Mathematics 40S, Applied Mathematics 40S, MATH-0042 or the former MATH-0040.

RESTRICTIONS: A student may not receive credit for MATH-1102 (3) and any of the following: MATH-1101 (6), MATH-1103(3) OR MATH-1104(3).

NOTE: Students intending to take senior courses in Mathematics, Statistics, Physics, Chemistry, or similar scientific and technical areas should not take MATH-1102 (which is a terminal course). Such students should take MATH-1101 (6) or both MATH-1103(3) AND MATH-1104(3).

MATH-1103(3) INTRODUCTION TO CALCULUS I (Le3, La 1.5)

This course covers differential calculus of a function of one variable. Topics include: limits, continuity, and the differentiation of algebraic, trigonometric, inverse trigonometric, exponential and logarithmic functions. Applications include curve sketching, optimization problems, and related rate problems. The combined material from MATH-1103(3) Introduction to Calculus I and MATH-1104(3) Introduction to Calculus II is equivalent to MATH-1101 (6) Introduction to Calculus.

PREREQUISITE: Pre-Calculus Mathematics 40S, MATH-0042 or the former MATH-0040 or permission of the instructor or Department Chair.

RESTRICTIONS: A student may not receive credit for more than one of MATH-1101 (6), MATH-1102 (3), or MATH-1103(3).

NOTE: Students who have not obtained a minimum grade of 60% in Pre-Calculus 40S are strongly advised to take MATH-0042 Mathematics Access II prior to registering in MATH-1103(3).

MATH-1104(3) INTRODUCTION TO CALCULUS II (Le3, La1.5)

This course covers single variable integral calculus. Topics include: definite and indefinite integrals, the natural logarithm defined as an integral, L'Hôpital's rule, techniques of integration, and improper integrals. Applications covered include areas between curves, volumes of solids of revolution, and arc length of a curve. The combined material from MATH-1103(3) Introduction to Calculus I and MATH-

1104(3) Introduction to Calculus II is equivalent to MATH-1101 (6) Introduction to Calculus.

PREREQUISITE: Minimum grade of C in MATH-1103(3) or permission of instructor or Department Chair.

RESTRICTIONS: A student may not receive credit for more than one of MATH-1101 (6), MATH-1102 (3), or MATH-1104(3).

MATH-1201(3) LINEAR ALGEBRA I (Le3) This is an introduction to fundamental results concerning systems of linear equations, matrices, determinants, properties of complex numbers, vector geometry, and vector space properties of n-dimensional Euclidean space.

PREREQUISITE: Pre-Calculus Mathematics 40S or Applied Mathematics 40S, MATH-0042 or the former MATH-0040.

RESTRICTIONS: A student may not receive credit for both MATH-1201(3) and the former MATH-2201(6).

MATH-1401(3) DISCRETE MATHEMATICS (Le3, La1.5)

This course covers logic (simple and compound statements, truth tables, logical equivalence, quantifiers); proof methods (direct, contrapositive, contradiction); elementary set theory (subsets, unions, intersections, set difference, power sets, Cartesian products); basic number theory (divisibility, the division algorithm, and Euclidean algorithm); mathematical induction; relations (binary, equivalence -- including congruence modulo n, partial orders); functions (well-defined, one-to-one, onto, bijective, compositions, inverses, images and inverse images of sets); counting (inclusion-exclusion principle, addition and multiplication principles, pigeonhole principle, permutations, combinations, the binomial theorem). This course is intended for students planning to major in Mathematics.

PREREQUISITE: One of Pre-Calculus Mathematics 40S, Applied Mathematics 40S, MATH-0042 or the former MATH-0040.

MATH-2102(3) DIFFERENTIAL EQUATIONS I (Le3)

This is an introduction to differential equations including the following topics: solution of first order equations, reduction techniques, and solution of nth order linear differential equations. Most applications considered will be from Physics. Students who have already completed MATH-1201(3) or the former MATH-2201(6) should inform registration staff that they have standing in one of the corequisite courses

PREREQUISITE: MATH-1101(6) or both MATH-1103(3) AND MATH-1104(3).

COREQUISITES: MATH-1201(3) or the former MATH-2201(6).

MATH-2103(3) DIFFERENTIAL EQUATIONS II (Le3)

This course covers further concepts and methods of solving differential equations. The contents include: Laplace transform method, power series solutions (methods of Frobenius), matrix methods for systems of linear differential equations, and an introduction to partial differential equations including the method of separation of variables.

PREREQUISITE: MATH-2102(3).

COREQUISITES: MATH-2106(3) or the former MATH-2101(6), plus one of MATH-2203(3) (formerly MATH-2221(3)) or the former MATH-2201(6).

RESTRICTIONS: A student may not receive credit for both MATH-2103(3) and the former MATH-2112(3).

MATH-2105(3) INTERMEDIATE CALCULUS I (Le3)

Topics covered are selected from the following list: Formal definition of a limit, limit theorems, sequences, infinite series (convergence tests, power series, Taylor's theorem), parametric equations, polar coordinates. Students who have already completed MATH-1201(3) or the former MATH-2201(6) should inform registration staff that

they have standing in one of the corequisite courses.

PREREQUISITE: A grade of at least C in MATH-1101(6) or in both MATH-1103(3) AND MATH-1104(3).

COREQUISITES: MATH-1201(3) or the former MATH-2201(6).

NOTE: Mathematics majors are strongly advised to take MATH-2105(3) in their second year of studies.

RESTRICTIONS: A student may not receive credit for both MATH-2105(3) and the former MATH-2101(6).

MATH-2106(3) INTERMEDIATE CALCULUS II (Le3)

Topics covered are selected from the following list:

Multivariable functions: limits and continuity, partial derivatives, gradient, extrema, Lagrange Multipliers; Multiple integrals: double and triple integrals, applications, change of variable, cylindrical and spherical coordinates, Jacobians; vector functions and vector calculus.

PREREQUISITE: MATH-2105(3) and MATH-1201(3) or the former MATH-2201(6)

RESTRICTIONS: A student may not receive credit for both MATH-2106(3) and the former MATH-2101(6).

Note: Mathematics majors are strongly advised to take MATH-2106(3) in their second year of studies.

MATH-2202(3) APPLIED ALGEBRA (Le3)

This course will introduce students to modern applications of algebraic structures. It begins with a study of the fundamental properties of finite fields and their relationship with geometry. The course continues by studying such applications as error-correcting codes, cryptography, design of experiments and fast arithmetic.

PREREQUISITES: MATH-1201(3) and MATH-1401(3) or permission of instructor.

RESTRICTIONS: A student may not receive credit for both MATH-2202(3) and the former MATH-2301(3).

MATH-2203(3) LINEAR ALGEBRA II (Le3)

This course covers finite dimensional vector spaces; linear transformations and matrices; change of bases; eigenvalues and eigenvectors and diagonalization.

PREREQUISITES: MATH-1201(3) and MATH-1101(6) or both MATH-1103(3) AND MATH-1104(3).

RESTRICTIONS: A student may not receive credit for both this course and the former MATH-2201(6) or the former MATH-2221(3).

MATH-2305(3) PHILOSOPHY AND MATHEMATICS (Le3)

Historically, philosophers have been intrigued by mathematics. Some philosophers, such as Pythagoras, Descartes and Frege, have made fundamental contributions to mathematics while mathematicians and physicists such as Heisenberg, Einstein and Hawking have noticed that contemporary aspects of their disciplines have raised ancient philosophical questions anew. Are mathematical proofs "certain"? Is mathematics independent of empirical experience? Can mathematics be reduced to logic? Does mathematics describe reality? This course examines such questions and the answers offered in the history of philosophy.

CROSS-LISTED: Philosophy PHIL-2305(3).

NOTE: This course may NOT be used to fulfil the Science Requirement.

MATH-2501(3) INTRODUCTION TO NUMBER THEORY (Le3)

This course explores properties of integers, linear Diophantine equations, Fermat's Theorem, congruences, and quadratic residues.

PREREQUISITES: MATH-1401(3) and an additional 3 credit hour or 6 credit hour course in Mathematics at the 1000 level or above.

MATH-2701(3) LINEAR OPTIMIZATION (Le3) Topics for this course are selected from the Simplex algorithm, game

theory, sensitivity analysis, duality theory, and efficient implementations of Simplex.

PREREQUISITES: MATH-2203(3) (formerly MATH-2221(3)), the former MATH-2201(6) or permission of instructor.

RESTRICTIONS: A student may not receive credit for this course and the former MATH-4702(3) or MATH-4702(6).

MATH-2803(3) SCIENTIFIC COMPUTING FOR

MATHEMATICS (Le3, La2) This course is an introduction to some of the many aspects of computers, from the design and implementation of computer hardware, machine language, compiler and language theory to the design, analysis, and implementation of algorithms. The course can be an introduction to computer programming (through a specific programming language such as C or C++) with focus on algorithms of importance to mathematics, e.g. numerical algorithms from Calculus such as Newton-Raphson, Simpson's rule, and numerical linear algebra. The course may also introduce students to specialized mathematical applications, e.g. MAPLE. Other topics may be covered at the discretion of the instructor.

PREREQUISITES: MATH-1201 (3) and either MATH-1101 (6), MATH-1102 (3) or MATH-1104(3).

MATH-2901(3) HISTORY OF CALCULUS (Le3)

This course gives an overview of the main ideas of Calculus, together with their historical development. It will investigate issues such as the definition of Calculus; how and when it developed; what problems inspired its creation; and how it changed the way mathematicians and others think about mathematical knowledge. Readings of original sources in English translation may range from Babylonian mathematical tablets, through Euclid and the Greeks, past Galileo, Leibniz and Newton, to Cauchy, Riemann and Robinson.

PREREQUISITES: Pre-Calculus Mathematics 40S, Applied Mathematics 40S, MATH-0042 or the former MATH-0040.

RESTRICTIONS: Education students in the Early, Early/Middle and/or Middle Years Streams cannot use this course to satisfy the math distribution requirement unless they have also received credit for an additional Mathematics course at the 1000 level or higher, excluding MATH-2902(3). For all other students, this course can be used to fulfil either the Science Requirement or the Humanities Requirement.

CROSS-LISTED: Philosophy PHIL-2901(3).

NOTE: This course can be used to fulfil either the Science Requirement or the Humanities Requirement.

MATH-2902(3) MATHEMATICS PRIOR TO 1640 (Le3)

This course examines selected topics in mathematics and traces their development in the Old World prior to 1640. It focuses on the theory and methodologies of algebra, number theory, trigonometry, and combinatorics. As well, the course reviews geometry and number systems. Students are expected to solve problems and prove certain theorems.

PREREQUISITES: Consumer Mathematics 40S, Pre-Calculus Mathematics 40S, Applied Mathematics 40S, MATH-0042 or the former MATH-0040.

MATH-2903(3) MATHEMATICS FOR EARLY/MIDDLE

YEARS TEACHERS (Le3, La2) This course is for students planning to become elementary teachers who wish to gain a more thorough understanding of the mathematics underpinning many of the topics taught in the K-8 curriculum. Topics include discrete mathematics (logic, sets, proof techniques), number theory (numeration systems, Euclidean algorithm, prime factorization), Euclidean geometry (Euclid's axioms, congruence, Pythagorean Theorem) and combinatorics (counting and probability, Pascal's triangle).

PREREQUISITES: At least one of Pre-Calculus Mathematics 40S or MATH-0042 or the former MATH-0040 or a grade of 65% or higher in Applied Mathematics 40S or a grade of

65% or higher in MATH-0041.

RESTRICTIONS: This course may not be used towards the major or minor requirement for a degree in Mathematics. Students who are not registered in the Faculty of Education may not register in this course.

MATH-3101(6) ADVANCED CALCULUS AND ANALYSIS

(Le3) This course studies construction of the reals, uniform convergence and sup-norms, Stone-Weierstrass theorem, theory of integration, Fourier analysis, line and surface integrals, Green's, Gauss' and Stoke's theorems.

PREREQUISITE: MATH-1401(3), MATH-2106(3) (or the former MATH-2101(6)), and MATH-2203(3) (or the former MATH-2201(6) or MATH-2221(3)).

MATH-3103(3) METHODS IN ADVANCED CALCULUS

(Le3) This course covers methods and applications of advanced calculus. Topics are chosen from: differentiation and integration of vector valued functions; arc length and speed; curvature and general motion in 3-dimensional space; vector fields, line integrals and surface integrals; the fundamental theorems of vector analysis (Green's Theorem, Stokes' Theorem, and the Divergence Theorem); Fourier series and other topics in harmonic analysis

PREREQUISITE: MATH-2106(3) or the former MATH-2101(6)

MATH-3202(3) GROUP THEORY (Le3) This course studies symmetry groups of regular polygons and Platonic solids, permutations and permutation groups; abstract groups, Cosets, Homomorphisms, Subgroups, Normal subgroups and quotient groups; isomorphism theorems, Sylow theorems, classification of finitely generated Abelian groups; group actions and counting with Burnside's lemma.

PREREQUISITES: MATH-1401(3) and MATH-2203(3) or the former MATH-2221(3) or the former MATH-2201(6)

RESTRICTIONS: A student may not receive credit for this course and MATH-4201(6) or the former MATH-3201(6).

MATH-3203(3) LINEAR ALGEBRA III (Le3) This course introduces students to inner product spaces; properties of Hermitian and normal matrices; unitary matrices; factorization theorems; Schur's Theorem; the Spectral Theorem; the Cayley-Hamilton Theorem; and quadratic forms. At the discretion of the instructor, other advanced topics in linear algebra may be covered.

PREREQUISITES: MATH-1401(3) and MATH-2203(3) or the former MATH-2201(6)

MATH-3401(3) GRAPH THEORY (Le3) This course includes the following topics: graph isomorphism, shortest path problem, Euler tours, trees, graph colourings and bipartite matchings.

PREREQUISITES: MATH-1401(3) or permission of instructor.

RESTRICTIONS: A student may not receive credit for this course and the former MATH-2011(3).

MATH-3402(3) COMBINATORICS (Le3) This course includes the following topics: generating functions and recurrence relations, the principle of inclusion and exclusion, symmetric groups, finite fields, and combinatorial designs.

PREREQUISITES: MATH-1401(3) plus one of MATH-1101(6), MATH-1102(3), MATH-1103(3) or MATH-1104(3).

RESTRICTIONS: A student may not receive credit for this course and the former MATH-2022(3).

MATH-3403(3) MATHEMATICAL LOGIC (Le3) This course introduces the student to mathematical logic. Course topics include propositional calculus, first order logic, completeness, compactness, decidability, Gödel's Incompleteness theorem and models.

PREREQUISITES: MATH-1401(3) plus one of MATH-3401(3) (formerly MATH-2011(3)), MATH-3402(3) (formerly MATH-

2022(3)), MATH-2203(3) (formerly MATH-2221(3)), the former MATH-2201(6), or MATH-2501(3).

RESTRICTIONS: A student may not receive credit for this course and the former MATH-3401(3).

MATH-3412(3) INTRODUCTION TO OPERATIONS RESEARCH (Le3)

This course provides a practical introduction to the formulation and solution of some economics and industrial problems using Operations Research models. It emphasizes model-building and problem-solving using computer packages. Topics covered are chosen from linear programming, transportation, assignment and transshipment problems, network models, integer programming, nonlinear programming, decision making, inventory models, and queueing theory.

PREREQUISITES: MATH-1201(3), the former MATH-2201(6) or ECON-3201(3), or permission of instructor.

CROSS-LISTED: Statistics STAT-3412(3)

MATH-3611(3) MATHEMATICAL STATISTICS I (Le3) The course provides students with a firm foundation in probability theory, which is necessary for a complete understanding of any advanced statistics. Topics include counting, joint and conditional distributions, random variables, and special distributions.

PREREQUISITES: STAT-1301(3) and STAT-1302(3) or the former STAT-1201(6), or both STAT-1501(3) and STAT-1601(3) or STAT-2001(3), and MATH-2106(3) or the former MATH-2101(6).

RESTRICTIONS: A student may not receive credit for this course and the former STAT-2701(3) or the former STAT-3201(3).

CROSS-LISTED: Statistics STAT-3611(3).

MATH-3612(3) MATHEMATICAL STATISTICS II (Le3)

In this course students study the continuous probability distributions and their general properties, distributions of functions of random variables, sampling distributions, including t and F, and an introduction to estimation and theory of hypotheses testing.

PREREQUISITES: MATH/STAT-3611(3) (formerly STAT-3201(3)) (or the former STAT-2701(3)).

RESTRICTIONS: A student may not receive credit for this course and the former STAT-3201(6) or STAT-3202(3).

CROSS-LISTED: Statistics STAT-3612(3).

MATH-3701(3) NUMERICAL METHODS (Le3, LaV)

Methods for finding roots of functions, numerical differentiation and numerical integration, interpolation and polynomial approximation, solving systems of equations, and solving the initial value problem in ordinary differential equations are studied in this course. Computer programming is used to implement the relevant numerical algorithms.

PREREQUISITES: MATH-2102(3) and MATH-2106(3) or the former MATH-2101(6) and either MATH-1201(3) or MATH-2203(3) for the former MATH-2201(6).

RESTRICTIONS: A student may not receive credit for this course and the former MATH-3701(6).

MATH-3703(3) MATHEMATICAL MODELLING (Le3)

A variety of deterministic models are studied using techniques from calculus, linear algebra, and differential equations. Models are selected from the following areas: physical sciences, life sciences, social sciences, and management sciences

PREREQUISITES: MATH-2106(3) or the former MATH-2101(6), MATH-2203(3) (formerly MATH-2221(3)) or the former MATH-2201(6), and MATH-2103(3) (formerly MATH-2112(3)).

MATH-4001(6) DIRECTED READINGS IN MATHEMATICS

(D) This is a reading course available only to students in their third or fourth year. A topic is arranged by mutual

written agreement between the student and a Supervisor. The student is required to meet the Supervisor weekly.

PREREQUISITES: A minimum GPA of 3.0 in all mathematics courses, at least one 3000-level course and written permission of the instructor and the Department Chair.

MATH-4003(3) TOPICS IN MATHEMATICS (Le3) This course covers an area in mathematics as selected by the instructor. Possible topics may be in algebraic combinatorics, functional analysis, Galois theory, representation theory, or advanced topics in combinatorics, graph theory, measure theory, or topology. Students should consult the instructor or the Department Chair for the current topic. This course may be repeated for credit when the topic varies.

PREREQUISITES: Permission of the instructor or the Department Chair.

MATH-4004(3) DIRECTED READINGS IN MATHEMATICS (D) This is a reading course available only to students in their third or fourth year. A topic is arranged by written agreement between the student and a Supervisor.

ADDITIONAL REQUIREMENTS: At least one 3000-level course in Mathematics. Written permission of the Instructor and Department Chair is required.

MATH-4101(3) COMPLEX ANALYSIS (Le3) This course studies construction of the complex numbers from the reals, Cauchy's theorems, Laurent Series, evaluating line integrals by means of residues, Cauchy-Riemann equations, conformal mapping, harmonic functions, Riemann sphere, Riemann surfaces, analytic continuation and monodromy theorem.

PREREQUISITES: MATH-2106(3) or the former MATH-2101(6) or permission of instructor.

RESTRICTIONS: A student may not receive credit for this course and the former MATH-3102(3).

MATH-4202(3) RINGS AND FIELDS (Le3) This course is a study of field axioms, finite and infinite fields, integral domains, fraction fields, division rings, abstract rings, polynomial rings, PID's and UFD's, Galois Theory; solvability of cubic and quartic, unsolvability of the quintic and other classical mathematical problems.

PREREQUISITES: MATH-3202(3)

RESTRICTIONS: A student may not receive credit for this course and MATH-4201(6) and the former MATH-3201(6).

MATH-4401(3) ADVANCED GRAPH THEORY AND COMBINATORIAL OPTIMIZATION (Le3) Topics covered in this course will be chosen from trees, connectivity, graph colourings, optimal matchings, packings and coverings, planar graphs, extremal graph theory, Ramsey theory, ordered sets.

PREREQUISITE: MATH-3401(3) (formerly MATH-2011(3)).

RESTRICTIONS: A student may not receive credit for this course and the former MATH-3013(3).

MATH-4402(3) NETWORKS AND THEIR APPLICATIONS (Le3) This course will introduce the student to a variety of network problems with emphasis on algorithmic aspects of these topics. Topics covered will be chosen from algorithmic complexity, search techniques, trees, Steiner trees and distances in networks, PERT networks, network flows and their applications.

PREREQUISITE: MATH-3401(3) (formerly MATH-2011(3)).

RESTRICTIONS: A student may not receive credit for this course and the former MATH-3015(3).

MATH-4403(3) SET THEORY (Le3) This course introduces concepts of set theory essential to modern mathematics. Topics include axioms for sets, infinite sets, cardinality,

ordinal and cardinal numbers, and ordered sets.

PREREQUISITES: MATH-1401(3) plus one of MATH-3401(3) (formerly MATH-2011(3)), MATH-3402(3) (formerly MATH-2022(3)), MATH-2203(3) (formerly MATH-2221(3)), the former MATH-2201(6), or MATH-2501(3).

RESTRICTIONS: A student may not receive credit for this course and the former MATH-3402(3), the former MATH-3601(3), or the former MATH-2402(6).

MATH-4601(3) INTRODUCTION TO TOPOLOGY AND ANALYSIS (Le3) In this course the basic concepts of topology are studied in the setting of metric spaces: open sets, convergence, continuity, connectedness, compactness, and completeness. The emphasis will be on Euclidean spaces, normed linear spaces, and function spaces, where the concepts of topology apply to mathematical analysis. Connections with and applications to analysis will be emphasized throughout, such as the monotone convergence theorem, the intermediate value property, the Heine-Borel property, Baire category, uniform boundedness, and the fixed-point property for complete metric spaces.

PREREQUISITES: MATH-3101(6).

RESTRICTIONS: A student may not receive credit for this course and the former MATH-3232(3) or MATH-3601(3).

MATH-4602(3) REAL ANALYSIS (Le3) Topics covered in this course will include normed linear spaces, Banach spaces and L_p spaces, Lebesgue measure and integration. This course will also cover classical results such as the Stone-Weierstrass theorem and the Ascoli Theorem.

COREQUISITE: MATH-3101(6).

RESTRICTIONS: A student may not receive credit for this course and the former MATH-3602(3).

MATH-4603(3) TOPOLOGY (Le3) This course is a study of topological spaces and their applications. Topics to be studied will include separation axioms, covering properties, product spaces, quotient spaces, filters, nets, convergence, compactness and connectedness.

COREQUISITE: MATH-3101(6)

RESTRICTIONS: A student may not receive credit for this course and the former MATH-3602(3).