Choice Based Credit System (CBCS)

UNIVERSITY OF DELHI

DEPARTMENT OF MATHEMATICS

UNDERGRADUATE PROGRAMME
(Courses effective from Academic Year 2015-16)

SYLLABUS OF COURSES TO BE OFFERED
Core Courses, Elective Courses & Ability Enhancement Courses

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Undergraduate Programme Secretariat

Preamble

The University Grants Commission (UGC) has initiated several measures to bring equity, efficiency and excellence in the Higher Education System of country. The important measures taken to enhance academic standards and quality in higher education include innovation and improvements in curriculum, teaching-learning process, examination and evaluation systems, besides governance and other matters.

The UGC has formulated various regulations and guidelines from time to time to improve the higher education system and maintain minimum standards and quality across the Higher Educational Institutions (HEIs) in India. The academic reforms recommended by the UGC in the recent past have led to overall improvement in the higher education system. However, due to lot of diversity in the system of higher education, there are multiple approaches followed by universities towards examination, evaluation and grading system. While the HEIs must have the flexibility and freedom in designing the examination and evaluation methods that best fits the curriculum, syllabi and teaching–learning methods, there is a need to devise a sensible system for awarding the grades based on the performance of students. Presently the performance of the students is reported using the conventional system of marks secured in the examinations or grades or both. The conversion from marks to letter grades and the letter grades used vary widely across the HEIs in the country. This creates difficulty for the academia and the employers to understand and infer the performance of the students graduating from different universities and colleges based on grades.

The grading system is considered to be better than the conventional marks system and hence it has been followed in the top institutions in India and abroad. So it is desirable to introduce uniform grading system. This will facilitate student mobility across institutions within and across countries and also enable potential employers to assess the performance of students. To bring in the desired uniformity, in grading system and method for computing the cumulative grade point average (CGPA) based on the performance of students in the examinations, the UGC has formulated these guidelines.

CHOICE BASED CREDIT SYSTEM (CBCS):

The CBCS provides an opportunity for the students to choose courses from the prescribed courses comprising core, elective/minor or skill based courses. The courses can be evaluated following the grading system, which is considered to be better than the conventional marks system. Therefore, it is necessary to introduce uniform grading system in the entire higher education in India. This will benefit the students to move across institutions within India to begin with and across countries. The uniform grading system will also enable potential employers in assessing the performance of the candidates. In order to bring uniformity in evaluation system and computation of the Cumulative Grade Point Average (CGPA) based on student's performance in examinations, the UGC has formulated the guidelines to be followed.

Outline of Choice Based Credit System:

1. **Core Course:** A course, which should compulsorily be studied by a candidate as a core requirement is termed as a Core course.
2. **Elective Course:** Generally a course which can be chosen from a pool of courses and which may be very specific or specialized or advanced or supportive to the discipline/ subject of study or which provides an extended scope or which enables an exposure to some other discipline/subject/domain or nurtures the candidate's proficiency/skill is called an Elective Course.
   - **2.1 Discipline Specific Elective (DSE) Course**: Elective courses may be offered by the main discipline/subject of study is referred to as Discipline Specific Elective. The University/Institute may also offer discipline related Elective courses of interdisciplinary nature (to be offered by main discipline/subject of study).
   - **2.2 Dissertation/Project**: An elective course designed to acquire special/advanced knowledge, such as supplement study/support study to a project work, and a candidate studies such a course on his own with an advisory support by a teacher/faculty member is called dissertation/project.
   - **2.3 Generic Elective (GE) Course**: An elective course chosen generally from an unrelated discipline/subject, with an intention to seek exposure is called a Generic Elective.

     P.S.: A core course offered in a discipline/subject may be treated as an elective by other discipline/subject and vice versa and such electives may also be referred to as Generic Elective.
3. **Ability Enhancement Courses (AEC)/Competency Improvement Courses/Skill Development Courses/Foundation Course:** The Ability Enhancement (AE) Courses may be of two kinds: AE Compulsory Course (AECC) and AE Elective Course (AEEC). "AECC" courses are the courses based upon the content that leads to Knowledge enhancement. They ((i) Environmental Science, (ii) English/MIL Communication) are mandatory for all disciplines. AEEC courses are value-based and/or skill-based and are aimed at providing hands-on-training, competencies, skills, etc.
   - **3.1** AE Compulsory Course (AECC): Environmental Science, English Communication/MIL Communication.
   - **3.2** AE Elective Course (AEEC): These courses may be chosen from a pool of courses designed to provide value-based and/or skill-based instruction.

Project work/Dissertation is considered as a special course involving application of knowledge in solving / analyzing /exploring a real life situation / difficult problem. A Project/Dissertation work would be of 6 credits. A Project/Dissertation work may be given in lieu of a discipline specific elective paper.

Details of courses under B.A (Honors), B.Com (Honors) & B.Sc. (Honors)

Course	*Credits	
	Theory+ Practical	Theory + Tutorial
I. Core Course		
(14 Papers)	14X4= 56	14X5=70
Core Course Practical / Tutorial*		
(14 Papers)	14X2=28	14X1=14
II. Elective Course		
(8 Papers)		
A.1. Discipline Specific Elective	4X4=16	4X5=20
(4 Papers)		
A.2. Discipline Specific Elective		
Practical/ Tutorial*	4 X 2=8	4X1=4
(4 Papers)		
B.1. Generic Elective/		
Interdisciplinary	4X4=16	4X5=20
(4 Papers)		
B.2. Generic Elective		
Practical/ Tutorial*	4 X 2=8	4X1=4
(4 Papers)		

- **Optional Dissertation or project work in place of one Discipline Specific** Elective **paper (6 credits) in 6th Semester**

III. Ability Enhancement Courses		
1. **Ability Enhancement Compulsory**		
(2 Papers of 2 credit each)	2 X 2=4	2 X 2=4
Environmental Science		
English/MIL Communication		
2. **Ability Enhancement Elective** (Skill Based)		
(Minimum 2)	2 X 2=4	2 X 2=4
(2 Papers of 2 credit each)		
Total credit	**140**	**140**

Institute should evolve a system/policy about ECA/ General Interest/Hobby/Sports/NCC/NSS/related courses on its own.

*** wherever there is a practical there will be no tutorial and vice-versa**

Structure

	Core Course (14)	Ability Enhancement Compulsory Course (AECC) (2)	Skill Enhancement Course (SEC) (2)	Elective Discipline Specific DSE (4)	Elective: Generic (4)
I	C 1 Calculus (including practicals)	(English communication/MIL) /Environmental Science			GE-1
	C 2 Algebra				
II	C 3 Real Analysis	(English communication/MIL) /Environmental Science			GE-2
	C 4 Differential Equations (including practicals)				
III	C 5 Theory of Real functions		SEC-1 LaTeX and		GE-3

			HTML		
	C 6 Group Theory-I				
	C 7 Multivariate Calculus (including practicals)				
IV	C 8 Partial Differential Equations (including practicals)		SEC-2 Computer Algebra Systems and Related Softwares		GE-4
	C 9 Riemann Integration & Series of functions				
	C 10 Ring Theory & Linear Algebra-I				
V	C 11 Metric Spaces			**DSE-1 (including practicals)** **(i)** Numerical Methods **or** (ii) Mathematical Modeling and Graph Theory **or** **(iii)** C++ Programming **DSE-2** (i) Mathematical Finance or (ii) Discrete Mathematics	

				or (iii) Cryptography and Network Security	
	C 12 Group Theory-II				
VI	C 13 Complex Analysis (including practicals)			**DSE-3** (i) Probability theory & Statistics or (ii) Mechanics or (iii) Bio-Mathematics **DSE-4** (i) Number Theory or (ii) Linear Programming and Theory of Games or (iii) Applications of Algebra	
	C 14 Ring Theory and Linear Algebra-II				

C1- Calculus (including practicals)

Total marks: 150
Theory: 75
Practical: 50
Internal Assessment: 25
5 Lectures, 4 Practicals (each in group of 15-20)

Hyperbolic functions, Higher order derivatives, Applications of Leibnitz rule.
[2]: Chapter 7 (Section 7.8)

The first derivative test, concavity and inflection points, Second derivative test, Curve sketching using first and second derivative test, limits at infinity, graphs with asymptotes. Graphs with asymptotes, L'Hopital's rule, applications in business, economics and life sciences.
[1]: Chapter 4 (Sections 4.3, 4.4, 4.5, 4.7)

Parametric representation of curves and tracing of parametric curves, Polar coordinates and tracing of curves in polar coordinates. Reduction formulae, derivations and illustrations of reduction formulae of the type , , , , ,
[1]: Chapter 9 (Section 9.4)
[2]: Chapter 11(Section 11.1), Chapter 8 (Sections 8.2-8.3, pages 532-538)

Volumes by slicing; disks and washers methods, Volumes by cylindrical shells. Arc length, arc length of parametric curves, Area of surface of revolution
[2]: Chapter 6 (Sections 6.2-6.5)
Techniques of sketching conics, reflection properties of conics, Rotation of axes and second degree equations, classification into conics using the discriminant
[2]: Chapter 11 (Section 11.4, 11.5) (Statements of Theorems 11.5.1 and 11.5.2)

Introduction to vector functions and their graphs, operations with vector-valued functions, limits and continuity of vector functions, differentiation and integration of vector functions. Modeling ballistics and planetary motion, Kepler's second law. Curvature, tangential and normal components of acceleration.
[1]: Chapter 10 (Sections 10.1-10.4)
[2]: Chapter 13 (Section 13.5)

Practical / Lab work to be performed on a computer:

Modeling of the following problems using Matlab / Mathematica / Maple etc.

1. Plotting of graphs of function of type (greatest integer function), , , , (even and odd positive integer), (even and odd positive integer), (a positive integer) , , , Discuss the effect of and on the graph.
2. Plotting the graphs of polynomial of degree 4 and 5, the derivative graph, the second derivative graph and comparing them.
3. Sketching parametric curves.
4. Tracing of conics in Cartesian coordinates.
5. Obtaining surface of revolution of curves.
6. Sketching ellipsoid, hyperboloid of one and two sheets, elliptic cone, elliptic paraboloid, hyperbolic paraboloid using Cartesian co-ordinates.
7. To find numbers between two real numbers and ploting of finite and infinite subset of R.
8. Matrix operations (addition, multiplication, inverse, transpose, determinant, rank, eigenvectors, eigenvalues, Characteristic equation and verification of Cayley Hamilton equation, system of linear equations)
9. Graph of Hyperbolic functions.
10. Computation of limit, differentiation and integration of vector functions.
11. Complex numbers and their representations, operations like addition, multiplication, division, modulus. Graphical representation of polar form.

REFERENCES:

1. M. J. Strauss, G. L. Bradley and K. J. Smith, Calculus (3rd Edition), Dorling Kindersley (India) Pvt. Ltd. (Pearson Education), Delhi, 2007.
2. H. Anton, I. Bivens and S. Davis, Calculus (7th Edition), John Wiley and sons (Asia), Pt Ltd., Singapore, 2002.

C2- Algebra

Total Marks: 100
Theory: 75
Internal Assessment: 25
5 Lectures, 1 Tutorial (per week per student)

Polar representation of complex numbers, nth roots of unity, De Moivre's theorem for rational indices and its applications.
[1]: Chapter 2

Equivalence relations, Functions, Composition of functions, Invertible functions, One to one correspondence and cardinality of a set, Well-ordering property of positive integers, Division algorithm, Divisibility and Euclidean algorithm, Congruence relation between integers , Principles of Mathematical Induction, statement of Fundamental Theorem of Arithmetic.
[2]: Chapter 2 (Section 2.4), Chapter 3, Chapter 4 (Sections 4.1 up to 4.1.6, 4.2 up to 4.2.11, 4.4 (till 4.4.8), 4.3.7 to 4.3.9), Chapter 5 (5.1.1, 5.1.4).

Systems of linear equations, row reduction and echelon forms, vector equations, the matrix equation Ax = b, solution sets of linear systems, applications of linear systems, linear independence. Introduction to linear transformations, matrix of a linear transformation, inverse of a matrix, characterizations of invertible matrices. Subspaces of R^n, dimension of subspaces of R^n and rank of a matrix, Eigen values, Eigen Vectors and Characteristic Equation of a matrix.
[3]: Chapter 1 (Sections 1.1-1.9), Chapter 2 (Sections 2.1-2.3, 2.8-2.9), Chapter 5 (Sections 5.1, 5.2).

REFERENCES:

1. Titu Andreescu and Dorin Andrica, Complex Numbers from A to …. Z, Birkhauser, 2006.
2. Edgar G. Goodaire and Michael M. Parmenter, Discrete Mathematics with Graph Theory(3rd Edition), Pearson Education (Singapore) Pvt. Ltd., Indian Reprint, 2005.
3. David C. Lay, Linear Algebra and its Applications (3rd Edition), Pearson Education Asia, Indian Reprint, 2007.

C3- Real Analysis

Total marks: 100
Theory: 75
Internal Assessment: 25
5 Lectures, 1 Tutorial (per week per student)

Algebraic and Order Properties of *R,* d-neighborhood of a point in *R,* Idea of countable sets, uncountable sets and uncountability of *R.*

[1]: Chapter 1 (Section 1.3), Chapter 2 (Sections 2.1, 2.2.7,2.2.8)

Bounded above sets, Bounded below sets, Bounded Sets, Unbounded sets, Suprema and Infima, The Completeness Property of *R,* The Archimedean Property, Density of Rational (and Irrational) numbers in *R,* Intervals.
[1]: Chapter 2 (Sections 2.3, 2.4, 2.5.)

Limit points of a set, Isolated points, Illustrations of Bolzano-Weierstrass theorem for sets.
[1]:Chapter 4(Section 4.1)

Sequences, Bounded sequence, Convergent sequence, Limit of a sequence. Limit Theorems, Monotone Sequences, Monotone Convergence Theorem. Subsequences, Divergence Criteria, Monotone Subsequence Theorem (statement only), Bolzano Weierstrass Theorem for Sequences. Cauchy sequence, Cauchy's Convergence Criterion.
[1]: Chapter 3 (Section 3.1-3.5)

Infinite series, convergence and divergence of infinite series, Cauchy Criterion,Tests for convergence: Comparison test, Limit Comparison test, Ratio Test, Cauchy's nth root test, Integral test, Alternating series, Leibniz test, Absolute and Conditional convergence.
[2]: Chapter 6 (Section 6.2)

REFERENCES:

1. R.G. Bartle and D. R. Sherbert, *Introduction to Real Analysis* (3rd Edition), John Wiley and Sons (Asia) Pvt. Ltd., Singapore, 2002.

2. Gerald G. Bilodeau , Paul R. Thie, G.E. Keough, *An Introduction to Analysis,* Jones & Bartlett, Second Edition, 2010.
3. Brian S. *Thomson*, Andrew. M. *Bruckner*, and Judith B. *Bruckner*, *Elementary Real Analysis,* Prentice Hall, 2001.

C4- Differential Equations (including practicals)

Total marks: 150

Theory: 75

Practical: 50

Internal Assessment: 25

5 Lectures, 4 Practicals (each in group of 15-20)

Differential equations and mathematical models, order and degree of a differential equation, exact differential equations and integrating factors of first order differential equations, reducible second order differential equations, application of first order differential equations to acceleration-velocity model, growth and decay model.

[2]: Chapter 1 (Sections 1.1, 1.4, 1.6), Chapter 2 (Section 2.3)

[3]: Chapter 2.

Introduction to compartmental models, lake pollution model (with case study of Lake Burley Griffin), drug assimilation into the blood (case of a single cold pill, case of a course of cold pills, case study of alcohol in the bloodstream), exponential growth of population, limited growth of population, limited growth with harvesting.

[1]: Chapter 2 (Sections 2.1, 2.5-2.8), Chapter 3 (Sections 3.1-3.3)

General solution of homogeneous equation of second order, principle of superposition for a homogeneous equation, Wronskian, its properties and applications, Linear homogeneous and non-homogeneous equations of higher order with constant coefficients, Euler's equation, method of undetermined coefficients, method of variation of parameters, applications of second order differential equations to mechanical vibrations.

[2]: Chapter 3 (Sections 3.1-3.5).

Equilibrium points, interpretation of the phase plane, predator-prey model and its analysis, competing species and its analysis, epidemic model of influenza and its analysis, battle model and its analysis.
[1]: Chapter 5 (Sections 5.1, 5.3-5.4, 5.6-5.7), Chapter 6.

***Practical / Lab work to be performed on a computer*:**
Modeling of the following problems using *Matlab / Mathematica / Maple* etc.

1. Plotting of second order solution family of differential equation.
2. Plotting of third order solution family of differential equation.
3. Growth model (exponential case only).
4. Decay model (exponential case only).
5.
   (a) Lake pollution model (with constant/seasonal flow and pollution concentration).
   (b) Case of single cold pill and a course of cold pills.
   (c) Limited growth of population (with and without harvesting).
6.
   (a) Predatory-prey model (basic volterra model, with density dependence, effect of DDT, two prey one predator).
   (b) Epidemic model of influenza (basic epidemic model, contagious for life, disease with carriers).
   (c) Battle model (basic battle model, jungle warfare, long range weapons).
7. Plotting of recursive sequences.
8. Find a value of that will make the following inequality holds for all :

(i) , (ii) ,

(ii) , (iv) etc.

9. Study the convergence of sequences through plotting.
10. Verify Bolzano Weierstrass theorem through plotting of sequences and hence identify convergent subsequences from the plot.
11. Study the convergence/divergence of infinite series by plotting their sequences of partial sum.

12. Cauchy's root test by plotting nth roots.

13. Ratio test by plotting the ratio of nth and n+1th term.

14. For the following sequences < >, given Find such that

(a)

(b)

(c)

(d)

(e)

15. For the following series , calculate

, and identify the convergent series (a)

(b) (c) (d) (e) (f)

(g) (h)

(j) (k) (l)

REFERENCES:

1. **Belinda Barnes** and **Glenn R. Fulford**, *Mathematical Modeling with Case Studies, A Differential Equation Approach Using Maple*, Taylor and Francis, London and New York, 2002.
2. **C. H. Edwards** and **D. E. Penny**, *Differential Equations and Boundary Value Problems: Computing and Modeling*, Pearson Education, India, 2005.
3. **S. L. Ross**, *Differential Equations*, John Wiley and Sons, India, 2004.

C5 **Theory of Real Functions**

Total marks: 100
Theory: 75
Internal Assessment: 25
5 Lectures, 1 Tutorial (per week per student)

Limits of functions (epsilon-delta approach), sequential criterion for limits, divergence criteria. Limit theorems, one sided limits. Infinite limits & limits at infinity.
[1] Chapter 4, Section 4.1, Section 4.2, Section 4.3 (4.3.1 - 4.3.16)

Continuous functions, sequential criterion for continuity & discontinuity. Algebra of continuous functions.
[1] Chapter 5, Section 5.1, 5.2

Continuous functions on an interval, intermediate value theorem, location of roots theorem, preservation of intervals theorem.
[2]Art.18.1, 18.2, 18.3, 18.5, 18.6

Uniform continuity, non-uniform continuity criteria, uniform continuity theorem.
[1]Chapter 5, Section 5.4 **(**5.4.1 to 5.4.3)

Differentiability of a function at a point & in an interval, Carathéodory's theorem, algebra of differentiable functions.
[1]Chapter 6, Section 6.1 **(**6.1.1 to 6.1.7)

Relative extrema, interior extremum theorem. Rolle's theorem, Mean value theorem, intermediate value property of derivatives - Darboux's theorem. Applications of mean value theorem to inequalities & approximation of polynomials Taylor's theorem to inequalities.
[1] Chapter 6, Section 6.2 (6.2.1 to 6.2.7, 6.2.11, 6.2.12)

Cauchy's mean value theorem. Taylor's theorem with Lagrange's form of remainder, Taylor's theorem with Cauchy's form of remainder, application of Taylor's theorem to convex functions, relative extrema. Taylor's series & Maclaurin's series expansions of exponential & trigonometric functions, , .
[1] Chapter 6, Section 6.3 (6.3.2) Section 6.4 (6.4.1 to 6.4.6)

REFERENCES:

1. **R. G. Bartle & D.R. Sherbert,** Introduction to Real Analysis, John Wiley & Sons (2003)
2. **K. A. Ross,** Elementary Analysis: The Theory of Calculus, Springer (2004).

Suggestive Readings

1. **A. Mattuck,** Introduction to Analysis, Prentice Hall (1999).
2. **S. R. Ghorpade & B. V. Limaye**, A Course in Calculus and Real Analysis – Springer (2006).

C6 Group Theory –I

Total Marks: 100
Theory: 75
Internal Assessment: 25
5 Lectures, 1 Tutorial (per week per student)

Symmetries of a square, Dihedral groups, definition and examples of groups including permutation groups and quaternion groups (illustration through matrices), elementary properties of groups. Subgroups and examples of subgroups, centralizer, normalizer, center of a group, product of two subgroups. Properties of cyclic groups, classification of subgroups of cyclic groups.
[1]: Chapters 1, Chapter 2, Chapter 3 (including Exercise 20 on page 66 and Exercise 2 on page 86), Chapter 4.

Cycle notation for permutations, properties of permutations, even and odd permutations, alternating group, properties of cosets, Lagrange's theorem and consequences including Fermat's Little theorem. External direct product of a finite number of groups, normal subgroups, factor groups, Cauchy's theorem for finite abelian groups.
[1]: Chapter 5 (till end of Theorem 5.7), Chapter 7 (till end of Theorem 7.2, including Exercises 6 and 7 on page 168), Chapter 8 (till the end of Example 2), Chapter 9 (till end of Example 10, Theorem 9.3 and 9.5).

Group homomorphisms, properties of homomorphisms, Cayley's theorem, properties of isomorphisms, First, Second and Third isomorphism theorems.
[1]: Chapter 6 (till end of Theorem 6.2), Chapter 10.

REFERENCES:

1. Joseph A. Gallian, *Contemporary Abstract Algebra* (4th Edition), Narosa Publishing House, New Delhi, 1999.(IX Edition 2010)

SUGGESTED READING:

1. Joseph J. Rotman, An Introduction to the Theory of Groups (4th Edition), Springer Verlag, 1995.

C7 Multivariate Calculus (including practicals)

Total marks: 150
Theory: 75
Practical: 50
Internal Assessment: 25
5 Lectures, 4 Practicals (each in group of 15-20)

Functions of several variables, limit and continuity of functions of two variables. Partial differentiation, total differentiability and differentiability, sufficient condition for differentiability. Chain rule for one and two independent parameters, directional derivatives, the gradient, maximal and normal property of the gradient, tangent planes

[1]: Chapter 11 (Sections 11.1(Pages 541-543), 11.2-11.6)

Extrema of functions of two variables, method of Lagrange multipliers, constrained optimization problems, Definition of vector field, divergence and curl

[1]: Chapter 11(Sections 11.7 (Pages 598-605), 11.8(Pages 610-614))
Chapter 13 (Pages 684-689)

Double integration over rectangular region, double integration over nonrectangular region. Double integrals in polar co-ordinates, Triple integrals, Triple integral over a parallelepiped and solid regions. Volume by triple integrals, cylindrical and spherical co-ordinates. Change of variables in double integrals and triple integrals.

[1]: Chapter 12 (Sections 12.1, 12.2, 12.3, 12.4 (Pages 652-660), 12.5, 12.6)

Line integrals, Applications of line integrals: Mass and Work. Fundamental theorem for line integrals, conservative vector fields, independence of path. Green's theorem, surface integrals, integrals over parametrically defined surfaces. Stokes' theorem, The Divergence theorem.

[1]: Chapter 13 (Section 13.2, 13.3, 13.4(Page 712–716), 13.5(Page 723–726, 729-730), 13.6 (Page 733–737), 13.7 (Page 742–745))

REFERENCES:

1. M. J. Strauss, G. L. Bradley and K. J. Smith, Calculus (3rd Edition), Dorling Kindersley (India) Pvt. Ltd. (Pearson Education), Delhi, 2007.

SUGGESTED READING:

2. E. Marsden, A. J. Tromba and A. Weinstein, *Basic multivariable calculus,* Springer (SIE), Indian reprint, 2005.

***Practical / Lab work to be performed on a computer*:**

Modeling of the following problems using *Matlab / Mathematica / Maple* etc.

1. Draw the following surfaces and find level curves at the given heights:

(i) ,

(ii) , (iii) ,

(iv)

(v) ,

(vi) .

2. Draw the following surfaces and discuss whether limit exits or not as approaches to the given points. Find the limit, if it exists:

(i) ,

(ii)

(iii) ,

(iv) ,

(v) ,

(vi) ,

(vii) ,

(viii)

3. Draw the tangent plane to the following surfaces at the given point:

(i) , (ii) ,

(iii) ,

(iv) ,

(v) .

4. Use an incremental approximation to estimate the following functions at the given point and compare it with calculated value:

(i) , (ii) ,

(iii) ,

(iv) .

5. Find critical points and identify relative maxima, relative minima or saddle points to the following surfaces, if it exist:

(i) , (ii) , (iii) , (iv) .

6. Draw the following regions **D** and check whether these regions are of **Type I** or **Type II**:

(i) ,

(ii) ,

7. Illustrations of the following :

1. Let be any function and be any number. For given and , find a such that for all satisfying , the inequality holds. For examples:

(i)

(ii)

(iii)

(iv)

8. Discuss the limit of the following functions when tends to 0: .

9. Discuss the limit of the following functions when tends to infinity :

10. Discuss the continuity of the functions at in practical 2.

11. Illustrate the geometric meaning of Rolle's theorem of the following functions on the given interval :

12. Illustrate the geometric meaning of Lagrange's mean value theorem of the following functions on the given interval:

13. For the following functions and given , if exists, find such that and discuss uniform continuity of the functions:

(i)

(ii)

(iii)

(iv)

(v)

(vi)

(vii)

14. Verification of Maximum –Minimum theorem, boundedness theorem & intermediate value theorem for various functions and the failure of the conclusion in case of any of the hypothesis is weakened.

15. Locating points of relative & absolute extremum for different functions

16. Relation of monotonicity & derivatives along with verification of first derivative test.

17. Taylor's series - visualization by creating graphs:

a. Verification of simple inequalities
b. Taylor's Polynomials – approximated up to certain degrees
c. Convergence of Taylor's series
d. Non-existence of Taylor series for certain functions
e. Convexity of the curves

C8 Partial Differential Equations (including practicals)

Total marks: 150
Theory: 75
Practical: 50
Internal Assessment: 25
5 Lectures, 4 Practicals (each in group of 15-20)

Introduction, classification, construction and geometrical interpretation of first order partial differential equations (PDE), method of characteristic and general solution of first order PDE, canonical form of first order PDE, method of separation of variables for first order PDE.
[1]: Chapter 2.

Mathematical modeling of vibrating string, vibrating membrane, conduction of heat in solids, gravitational potential, conservation laws and Burger's equations, classification of second order PDE, reduction to canonical forms, equations with constant coefficients, general solution.
[1]: Chapter 3 (Sections 3.1-3.3, 3.5-3.7), Chapter 4.

Cauchy problem for second order PDE, homogeneous wave equation, initial boundary value problems, non-homogeneous boundary conditions, finite strings with fixed ends, non-homogeneous wave equation, Riemann problem, Goursat problem, spherical and cylindrical wave equation.
[1]: Chapter 5.

Method of separation of variables for second order PDE, vibrating string problem, existence and uniqueness of solution of vibrating string problem, heat conduction problem, existence and uniqueness of solution of heat conduction problem, Laplace and beam equation, non-homogeneous problem.

[1]: Chapter 7.

***Practical / Lab work to be performed on a computer*:**

Modeling of the following problems using *Matlab / Mathematica / Maple* etc.

1. Solution of Cauchy problem for first order PDE.

2. Plotting the characteristics for the first order PDE.

3. Plot the integral surfaces of a given first order PDE with initial data.

4. Solution of wave equation for any 2 of the following associated conditions:

(a)

(b) ,

(c) ,

(d) ,

5. Solution of one-Dimensional heat equation , for a homogeneous rod of length l.

That is - solve the IBVP:

6. Solving systems of ordinary differential equations.

7. Approximating solution to Initial Value Problems using any of the following approximate methods:

(a) The Euler Method

(b) The Modified Euler Method.

(c) The Runge-Kutta Method.

Comparison between exact and approximate results for any representative differential equation.

8. Draw the following sequence of functions on given the interval and discuss the pointwise convergence:

(i) , (ii) ,

(iii) , (iv)

(v) , (vi) ,

(Vii) ,

(viii)

9. Discuss the uniform convergence of sequence of functions above.

REFERENCE:

1. **Tyn Myint-U** and **Lokenath Debnath,** *Linear Partial Differential Equation for Scientists and Engineers,* Springer, Indian reprint, 2006.

SUGGESTED READING:

1. **Ioannis P Stavroulakis** and **Stepan A Tersian**, *Partial Differential Equations: An Introduction with Mathematica and MAPLE*, World Scientific, Second Edition, 2004.

C9 Riemann Integration & Series of Functions

Total marks: 100
Theory: 75
Internal Assessment: 25
5 Lectures, 1 Tutorial (per week per student)

Riemann integration; inequalities of upper and lower sums; Riemann conditions of integrability. Riemann sum and definition of Riemann integral through Riemann sums; equivalence of two definitions; Riemann integrability of monotone and continuous functions, Properties of the Riemann integral; definition and integrability of piecewise continuous and monotone functions. Intermediate Value theorem for Integrals; Fundamental theorems of Calculus.
[1] Chapter 6 (Art. 32.1 to 32.9, 33.1, 33.2, 33.3, 33.4 to 33.8, 33.9, 34.1, 34.3)

Improper integrals; Convergence of Beta and Gamma functions.
[3] Chapter 7 (Art. 7.8)

Pointwise and uniform convergence of sequence of functions. Theorems on continuity, derivability and integrability of the limit function of a sequence of functions.
[2] Chapter 8, Section 8.1, Section 8.2 (8.2.1 – 8.2.2), Theorem 8.2.3, Theorem 8.2.4 and Theorem 8.2.5

Series of functions; Theorems on the continuity and derivability of the sum function of a series of functions; Cauchy criterion for uniform convergence and Weierstrass M-Test
[2] Chapter 9, Section 9.4 (9.4.1 to 9.4.6)

Limit superior and Limit inferior. Power series, radius of convergence, Cauchy Hadamard Theorem, Differentiation and integration of power series; Abel's Theorem; Weierstrass Approximation Theorem.
[1] Chapter 4, Art. 26 (26.1 to 26.6), Theorem 27.5

REFERENCES:

1. K.A. Ross, Elementary Analysis: The Theory of Calculus, Undergraduate Texts in Mathematics, Springer (SIE), Indian reprint, 2004.
2. R.G. Bartle D.R. Sherbert, Introduction to Real Analysis (3rd edition), John Wiley and Sons (Asia) Pvt. Ltd.., Singapore, 2002.
3. Charles G. Denlinger, Elements of Real Analysis, Jones and Bartlett (Student Edition),2011.

C 10 Ring Theory & Linear Algebra-I

Total Marks: 100
Theory: 75
Internal Assessment: 25
5 Lecture, 1 Tutorial (per week per student)

Definition and examples of rings, properties of rings, subrings, integral domains and fields, characteristic of a ring. Ideals, ideal generated by a subset of a ring, factor rings, operations on ideals, prime and maximal ideals. Ring homomorphisms, properties of ring homomorphisms, Isomorphism theorems I, II and III, field of quotients.
[2]: Chapter 12, Chapter 13, Chapter 14, Chapter 15.

Vector spaces, subspaces, algebra of subspaces, quotient spaces, linear combination of vectors, linear span, linear independence, basis and dimension, dimension of subspaces. Linear transformations, null space, range, rank and nullity of a linear transformation, matrix representation of a linear transformation, algebra of linear transformations. Isomorphisms, Isomorphism theorems, invertibility and isomorphisms, change of coordinate matrix.
[1]: Chapter 1 (Sections 1.2-1.6, Exercise 29, 33, 34, 35), Chapter 2 (Sections 2.1-2.5).

REFERENCES:

1. Stephen H. Friedberg, Arnold J. Insel, Lawrence E. Spence, *Linear Algebra* (4th Edition), Prentice-Hall of India Pvt. Ltd., New Delhi, 2004.
2. Joseph A. Gallian, *Contemporary Abstract Algebra* (4th Edition), Narosa Publishing House, New Delhi, 1999.

SUGGESTED READING:

1. S Lang, Introduction to Linear Algebra (2nd edition), Springer, 2005
2. Gilbert Strang, Linear Algebra and its Applications, Thomson, 2007
3. S. Kumaresan, Linear Algebra- A Geometric Approach, Prentice Hall of India, 1999.
4. Kenneth Hoffman, Ray Alden Kunze, Linear Algebra 2nd Ed., Prentice-Hall Of India Pvt. Limited, 1971

C 11 Metric Spaces

Total marks: 100
Theory: 75
Internal Assessment: 25
5 Lectures, 1 Tutorial (per week per student)

Metric spaces: definition and examples. Sequences in metric spaces, Cauchy sequences. Complete Metric Spaces.
[1] Chapter1, Section 1.2 (1.2.1 to 1.2.6). Section 1.3, Section 1.4 (1.4.1 to 1.4.4), Section 1.4 (1.4.5 to 1.4.14 (ii)).

Open and closed balls, neighbourhood, open set, interior of a set, Limit point of a set, closed set, diameter of a set, Cantor's Theorem, Subspaces, dense sets, separable spaces.
[1] Chapter2, Section 2.1 (2.1.1 to 2.1.16), Section 2.1 (2.1.17 to 2.1.44), Section 2.2, Section 2.3 (2.3.12 to 2.3.16)

Continuous mappings, sequential criterion and other characterizations of continuity, Uniform continuity, Homeomorphism, Contraction mappings, Banach Fixed point Theorem.
[1] Chapter3, Section 3.1, Section3.4 (3.4.1 to 3.4.8), Section 3.5 (3.5.1 to 3.5.7(iv)), Section 3.7 (3.7.1 to 3.7.5)

Connectedness, connected subsets of **R,** connectedness and continuous mappings.
[1] Chapter4, Section 4.1 (4.1.1 to 4.1.12)

Compactness, compactness and boundedness, continuous functions on compact spaces.
[1] Chapter5, Section 5.1 (5.1.1 to 5.1.6), Section 5.3 (5.3.1 to 5.3.11)

REFERENCES:

[1] Satish Shirali & Harikishan L. Vasudeva, Metric Spaces, Springer Verlag London (2006) (First Indian Reprint 2009)

SUGGESTED READINGS:

[1] S. Kumaresan, Topology of Metric Spaces, Narosa Publishing House, Second Edition 2011.
[2] G. F. Simmons, Introduction to Topology and Modern Analysis, Mcgraw-Hill, Edition 2004.

C 12 Group Theory-II

Total Marks: 100
Theory: 75
Internal Assessment: 25
5 Lectures, 1 Tutorial (per week per student)

Automorphism, inner automorphism, automorphism groups, automorphism groups of finite and infinite cyclic groups, applications of factor groups to automorphism groups, Characteristic subgroups, Commutator subgroup and its properties.
[1]: Chapter 6, Chapter 9 (Theorem 9.4), Exersices1-4 on page168, Exercises 52, 58 on page Pg 188.

Properties of external direct products, the group of units modulo n as an external direct product, internal direct products, Fundamental Theorem of finite abelian groups.
[1]: Chapter 8, Chapter 9 (Section on internal direct products), Chapter 11.
Group actions, stabilizers and kernels, permutation representation associated with a given group action, Applications of group actions: Generalized Cayley's theorem, Index theorem. Groups acting on themselves by conjugation, class equation and consequences, conjugacy in S_n, *p*-groups, Sylow's theorems and consequences, Cauchy's theorem, Simplicity of A_n for $n \geq 5$, non-simplicity tests.
[2]: Chapter 1 (Section 1.7), Chapter 2 (Section 2.2), Chapter 4 (Section 4.1-4.3, 4.5-4.6).
[1]: Chapter 25.

REFERENCES:

1. Joseph A. Gallian, Contemporary Abstract Algebra (4th Ed.), Narosa Publishing House, 1999.
2. David S. Dummit and Richard M. Foote, Abstract Algebra (3rd Edition), John Wiley and Sons (Asia) Pvt. Ltd, Singapore, 2004

C13 Complex Analysis (including practicals)

Total marks: 150

Theory: 75

Internal Assessment: 25

Practical: 50

5 Lectures, Practical 4 (in group of 15-20)

Limits, Limits involving the point at infinity, continuity.
Properties of complex numbers, regions in the complex plane, functions of complex variable, mappings. Derivatives, differentiation formulas, Cauchy-Riemann equations, sufficient conditions for differentiability.
[1]: Chapter 1 (Section 11), Chapter 2 (Section 12, 13) Chapter 2 (Sections 15, 16, 17, 18, 19, 20, 21, 22)

Analytic functions, examples of analytic functions, exponential function, Logarithmic function, trigonometric function, derivatives of functions, definite integrals of functions.
[1]: Chapter 2 (Sections 24, 25), Chapter 3 (Sections 29, 30, 34),Chapter 4 (Section 37, 38)

Contours, Contour integrals and its examples, upper bounds for moduli of contour integrals.
[1]: Chapter 4 (Section 39, 40, 41, 43)

Antiderivatives, proof of antiderivative theorem, Cauchy-Goursat theorem, Cauchy integral formula. An extension of Cauchy integral formula, consequences of Cauchy integral formula, Liouville's theorem and the fundamental theorem of algebra.
[1]: Chapter 4 (Sections 44, 45, 46, 50) , Chapter 4 (Sections 51, 52, 53)

Convergence of sequences and series, Taylor series and its examples. Laurent series and its examples, absolute and uniform convergence of power series, uniqueness of series representations of power series.
[1]: Chapter 5 (Sections 55, 56, 57, 58, 59, 60, 62, 63, 66)

Isolated singular points, residues, Cauchy's residue theorem, residue at infinity. Types of isolated singular points, residues at poles and its examples, definite integrals involving sines and cosines.
[1]: Chapter 6 (Sections 68, 69, 70, 71, 72, 73, 74), Chapter 7 (Section 85).

REFERENCES:

1. James Ward Brown and Ruel V. Churchill, Complex Variables and Applications (Eighth Edition), McGraw – Hill International Edition, 2009.

SUGGESTED READING:

2. Joseph Bak and Donald J. Newman, *Complex analysis* (2nd Edition), Undergraduate Texts in Mathematics, Springer-Verlag New York, Inc., New York, 1997.

LAB WORK TO BE PERFORMED ON A COMPUTER
(MODELING OF THE FOLLOWING PROBLEMS USING MATLAB/ MATHEMATICA/ MAPLE ETC.)

1. Declaring a complex number and graphical representation.

   e.g. Z_1 =3 + 4i, Z_2 = 4 – 7i

2. Program to discuss the algebra of complex numbers.

   e.g., if Z_1 =3 + 4i, Z_2 = 4 – 7i, then find $Z_1 + Z_2$, $Z_1 - Z_2$, $Z_1 * Z_2$,and Z_1 / Z_2

3. To find conjugate, modulus and phase angle of an array of complex numbers.

   e.g., Z = [2+ 3i   4-2i   6+11i   2-5i]

4. To compute the integral over a straight line path between the two specified end points.

   e. g., , where C is the straight line path from -1+ i to 2 - i.

5. To perform contour integration.

e.g., (i) , where C is the Contour given by $x = y^2 + 1$; .

(ii) , where C is the contour given by , which can be parameterized by x = cos (t), y = sin (t) for .

6. To plot the complex functions and analyze the graph .

e.g., (i) f(z) = Z

(ii) $f(z)=Z^3$

4. $f(z) = (Z^4-1)^{1/4}$

5. , etc.

7. To perform the Taylor series expansion of a given function f(z) around a given point z.

The number of terms that should be used in the Taylor series expansion is given for each function. Hence plot the magnitude of the function and magnitude of its Taylors series expansion.

e.g., (i) f(z) = exp(z) around z = 0, n =40.

(ii) $f(z)=\exp(z^2)$ around z = 0, n = 160.

8. To determines how many terms should be used in the Taylor series expansion of a given function f(z) around z = 0 for a specific value of z to get a percentage error of less than 5 %.

e.g., For f(z) = exp(z) around z =0, execute and determine the number of necessary terms to get a percentage error of less than 5 % for the following values of z:

(i) z = 30 + 30 i

(ii)

9. To perform Laurents series expansion of a given function f(z) around a given point z.

e.g., (i) $f(z)= (\sin z -1)/z^4$ around z = 0

(ii) $f(z) = \cot(z)/z^4$ around z = 0.

10. To compute the poles and corresponding residues of complex functions.

e.g.,

11. To perform Conformal Mapping and Bilinear Transformations.

C 14 Ring Theory and Linear Algebra – II

Total Marks : 100
Theory: 75
Internal Assessment: 25
5 Lectures, 1 Tutorial (per week per student)

Polynomial rings over commutative rings, division algorithm and consequences, principal ideal domains, factorization of polynomials, reducibility tests, irreducibility tests, Eisenstein criterion, unique factorization in Z[x].
Divisibility in integral domains, irreducibles, primes, unique factorization domains, Euclidean domains.
[1]: Chapter 16, Chapter 17, Chapter 18.

Dual spaces, dual basis, double dual, transpose of a linear transformation and its matrix in the dual basis, annihilators, Eigenspaces of a linear operator, diagonalizability, invariant subspaces and Cayley-Hamilton theorem, the minimal polynomial for a linear operator.
[2]: Chapter 2 (Section 2.6), Chapter 5 (Sections 5.1-5.2, 5.4), Chapter 7(Section 7.3).

Inner product spaces and norms, Gram-Schmidt orthogonalization process, orthogonal complements, Bessel's inequality, the adjoint of a linear operator, Least Squares Approximation, minimal solutions to systems of linear equations, Normal and self-adjoint operators, Orthogonal projections and Spectral theorem.
[2]: Chapter 6 (Sections 6.1-6.4, 6.6).

REFERENCES:

1. Joseph A. Gallian, Contemporary Abstract Algebra (4th Ed.), Narosa Publishing House, 1999.
2. Stephen H. Friedberg, Arnold J. Insel, Lawrence E. Spence, *Linear Algebra* (4th Edition), Prentice-Hall of India Pvt. Ltd., New Delhi, 2004.

SUGGESTED READING:

(Linear Algebra)
1. S Lang, Introduction to Linear Algebra (2nd edition), Springer, 2005
2. Gilbert Strang, Linear Algebra and its Applications, Thomson, 2007

3. S. Kumaresan, Linear Algebra- A Geometric Approach, Prentice Hall of India, 1999.
4. Kenneth Hoffman, Ray Alden Kunze, Linear Algebra 2nd Ed., Prentice-Hall Of India Pvt. Limited, 1971
(Ring theory and group theory)
1. John B.Fraleigh, A first course in Abstract Algebra, 7th Edition, Pearson Education India, 2003.
2. Herstein, Topics in Algebra (2nd edition), John Wiley & Sons, 2006
3. M ichael Artin, Algebra (2nd edition), Pearson Prentice Hall, 2011
4. Robinson, Derek John Scott., An introduction to abstract algebra, Hindustan book agency, 2010.

DSE-1 (including practicals): Any one of the following (at least two shall be offered by the college):

DSE-1(i) Numerical Methods

Total marks: 150
Theory: 75
Practical: 50
Internal Assessment: 25
5 Lectures, 4 Practicals (each in group of 15-20)

Algorithms, Convergence, Bisection method, False position method, Fixed point iteration method, Newton's method, Secant method, LU decomposition, Gauss-Jacobi, Gauss-Siedel and SOR iterative methods.
[1]: Chapter 1 (Sections 1.1-1.2), Chapter 2 (Sections 2.1-2.5), Chapter 3 (Section 3.5, 3.8).

Lagrange and Newton interpolation: linear and higher order, finite difference operators.
[1]: Chapter 5 (Sections 5.1, 5.3)
[2]: Chapter 4 (Section 4.3).

Numerical differentiation: forward difference, backward difference and central difference. Integration: trapezoidal rule, Simpson's rule, Euler's method.
[1]: Chapter 6 (Sections 6.2, 6.4), Chapter 7 (Section 7.2)

Note: Emphasis is to be laid on the algorithms of the above numerical methods.

Practical / Lab work to be performed on a computer:
Use of computer aided software (CAS), for example *Matlab / Mathematica / Maple* / *Maxima* etc., for developing the following Numerical programs:

(i) Calculate the sum 1/1 + 1/2 + 1/3 + 1/4 + ----------+ 1/ N.

(ii) To find the absolute value of an integer.

(iii) Enter 100 integers into an array and sort them in an ascending order.

(iv) Any two of the following

(a) Bisection Method
(b) Newton Raphson Method
(c) Secant Method
(d) Regulai Falsi Method

(v) LU decomposition Method

(vi) Gauss-Jacobi Method

(vii) SOR Method or Gauss-Siedel Method

(viii) Lagrange Interpolation or Newton Interpolation

(ix) Simpson's rule.

Note: For any of the CAS *Matlab / Mathematica / Maple* / *Maxima* etc., Data types-simple data types, floating data types, character data types, arithmetic operators and operator precedence, variables and constant declarations, expressions, input/output, relational operators, logical operators and logical expressions, control statements and loop statements, Arrays should be introduced to the students.

REFERENCES:

1. **B. Bradie**, *A Friendly Introduction to Numerical Analysis*, Pearson Education, India, 2007.
2. M**. K. Jain, S. R. K. Iyengar** and **R. K. Jain**, *Numerical Methods for Scientific and Engineering Computation*, New age International Publisher, India, 5th edition, 2007.

SUGGESTED READING:

1. **C. F. Gerald** and **P. O. Wheatley**, *App;ied Numerical Analysis*, Pearson Education, India,7th edition, 2008

DSE-1(ii) Mathematical Modeling & Graph Theory

Total marks: 150
Theory: 75
Practical: 50
Internal Assessment: 25
5 Lectures, 4 Practicals (each in group of 15-20)

Power series solution of a differential equation about an ordinary point, solution about a regular singular point, Bessel's equation and Legendre's equation, Laplace transform and inverse transform, application to initial value problem up to second order.
[2]: Chapter 7 (Sections 7.1-7.3), Chapter 8 (Sections 8.2-8.3).

Monte Carlo Simulation Modeling**:** simulating deterministic behavior (area under a curve, volume under a surface), Generating Random Numbers**:** middle square method, linear congruence, Queuing Models**:** harbor system, morning rush hour, Overview of optimization modeling, Linear Programming Model: geometric solution algebraic solution, simplex method, sensitivity analysis
[3]: Chapter 5 (Sections 5.1-5.2, 5.5), Chapter 7.

Graphs, diagraphs, networks and subgraphs, vertex degree, paths and cycles, regular and bipartite graphs, four cube problem, social networks, exploring and traveling, Eulerian and Hamiltonian graphs, applications to dominoes, diagram tracing puzzles, Knight's tour problem, gray codes.
[1]: Chapter 1 (Section 1.1), Chapter 2, Chapter 3.

Note: Chapter 1 (Section 1.1), Chapter 2 (Sections 2.1-2.4), Chapter 3 (Sections 3.1-3.3) are to be reviewed only. This is in order to understand the models on Graph Theory.

***Practical / Lab work to be performed on a computer*:**
Modeling of the following problems using *Matlab / Mathematica / Maple* etc.

(i) Plotting of Legendre polynomial for $n = 1$ to 5 in the interval [0,1]. Verifying graphically that all the roots of $P_n(x)$ lie in the interval [0,1].

(ii) Automatic computation of coefficients in the series solution near ordinary points

(iii) Plotting of the Bessel's function of first kind of order 0 to 3.

(iv) Automating the Frobenius Series Method

(v) Random number generation and then use it for one of the following

(a) Simulate area under a curve

(b) Simulate volume under a surface

(vi) Programming of either one of the queuing model

(a) Single server queue (e.g. Harbor system)

(b) Multiple server queue (e.g. Rush hour)

(vii) Programming of the Simplex method for 2/3 variables

REFERENCES:

1. **Joan M. Aldous** and **Robin J. Wilson**, *Graphs and Applications*: *An Introductory Approach*, Springer, Indian reprint, 2007.
2. **Tyn Myint-U** and **Lokenath Debnath**, *Linear Partial Differential Equation for Scientists and Engineers*, Springer, Indian reprint, 2006.
3. **Frank R. Giordano**, **Maurice D. Weir** and **William P. Fox**, *A First Course in Mathematical Modeling*, Thomson Learning, London and New York, 2003.

DSE-1(iii) C++ PROGRAMMING

Total marks: 150
Theory: 75
Practical: 50
Internal Assessment: 25
5 Lectures, 4 Practicals (each in group of 15-20)

Introduction to structured programming: data types- simple data types, floating data types, character data types, string data types, arithmetic operators and operators precedence, variables and constant declarations, expressions, input using the extraction operator >> and cin, output using the insertion operator << and cout, preprocessor directives, increment(++) and decrement(--) operations, creating a C++ program, input/ output, relational operators, logical operators and logical expressions, if and if-else statement, switch and break statements.

[1]Chapter 2(pages 37-95), Chapter3(pages 96 -129), Chapter 4(pages 134-178)

"for", "while" and "do-while" loops and continue statement, nested control statement, value returning functions, value versus reference parameters, local and global variables, one dimensional array, two dimensional array, pointer data and pointer variables,.

[1] Chapter 5 (pages 181 - 236), Chapter 6, Chapter 7(pages 287- 304()Chapter 9 (pages 357 - 390), Chapter 14 (pages 594 - 600).

Reference:

[1]D. S. Malik: C++ Programming Language, Edition-2009, Course Technology, Cengage Learning, India Edition

Suggested Readings:

[2]E. Balaguruswami: Object oriented programming with C++, fifth edition, Tata McGraw Hill Education Pvt. Ltd.

[3]Marshall Cline, Greg Lomow, Mike Girou: C++ FAQs, Second Edition, Pearson Education.

Note: Practical programs of the following (and similar) typeare suggestive.

1. Calculate the Sum of the series 1/1 + 1/2+ 1/3………………..+1/N for any positive integer N.
2. Write a user defined function to find the absolute value of an integer and use it to evaluate the function $(-1)^n/|n|$, for n = -2,-1,0,1,2.
3. Calculate the factorial of any natural number.
4. Read floating numbers and compute two averages: the average of negative numbers and the average of positive numbers.

5. Write a program that prompts the user to input a positive integer. It should then output a message indicating whether the number is a prime number.
6. Write a program that prompts the user to input the value of a, b and c involved in the equation ax^2 + bx + c = 0 and outputs the type of the roots of the equation. Also the program should outputs all the roots of the equation.
7. write a program that generates random integer between 0 and 99. Given that first two Fibonacci numbers are 0 and 1, generate all Fibonacci numbers less than or equal to generated number.
8. Write a program that does the following:
    a. Prompts the user to input five decimal numbers.
    b. Prints the five decimal numbers.
    c. Converts each decimal number to the nearest integer.
    d. Adds these five integers.
    e. Prints the sum and average of them.
9. Write a program that uses ***while***loops to perform the following steps:
    a. Prompt the user to input two integers :firstNum and secondNum (firstNum should be less than secondNum).
    b. Output all odd and even numbers between firstNum and secondNum.
    c. Output the sum of all even numbers between firstNum and secondNum.
    d. Output the sum of the square of the odd numbers firstNum and secondNum.
    e. Output all uppercase letters corresponding to the numbers between firstNum and secondNum, if any.
10. Write a program that prompts the user to input five decimal numbers. The program should then add the five decimal numbers, convert the sum to the nearest integer, and print the result.
11. Write a program that prompts the user to enter the lengths of three sides of a triangle and then outputs a message indicating whether the triangle is a right triangle or a scalene triangle.

12. Write a value returning function ***smaller*** to determine the smallest number from a set of numbers. Use this function to determine the smallest number from a set of 10 numbers.

13. Write a function that takes as a parameter an integer (as a **long** value) and returns the number of odd, even, and zero digits. Also write a program to test your function.

14. Enter 100 integers into an array and short them in an ascending/ descending order and print the largest/ smallest integers.

15. Enter 10 integers into an array and then search for a particular integer in the array.

16. Multiplication/ Addition of two matrices using two dimensional arrays.

17. Using arrays, read the vectors of the following type: A = (1 2 3 4 5 6 7 8) , B = (0 2 3 4 0 1 5 6) and compute the product and addition of these vectors.

18. Read from a text file and write to a text file.

19. Write a program to create the following grid using for loops:

```
1 2 3 4 5
2 3 4 5 6
3 4 5 6 7
4 5 6 7 8
5 6 7 8 9
```

20. Write a function, *reverseDigit*, that takes an integer as a parameter and returns the number with its digits reversed. For example, the value of function reverseDigit(12345) is 54321 and the value of reverseDigit(-532) is -235.

DSE-2: Any one of the following (at least two shall be offered by the college):

DSE-2(i) Mathematical Finance

Total Marks: 100
Theory: 75
Internal Assessment: 25
5 Lectures, 1 Tutorial (per week per student)

Basic principles: Comparison, arbitrage and risk aversion, Interest (simple and compound, discrete and continuous), time value of money, inflation, net present value, internal rate of return (calculation by bisection and Newton-Raphson methods), comparison of NPV and IRR. Bonds, bond prices and yields, Macaulay and modified duration, term structure of interest rates: spot and forward rates, explanations of term structure, running present value, floating-rate bonds, immunization, convexity, putable and callable bonds.
[1]: Chapter 1, Chapter 2, Chapter 3, Chapter 4.

Asset return, short selling, portfolio return, (brief introduction to expectation, variance, covariance and correlation), random returns, portfolio mean return and variance, diversification, portfolio diagram, feasible set, Markowitz model (review of Lagrange multipliers for 1 and 2 constraints), Two fund theorem, risk free assets, One fund theorem, capital market line, Sharpe index. Capital Asset Pricing Model (CAPM), betas of stocks and portfolios, security market line, use of CAPM in investment analysis and as a pricing formula, Jensen's index.
[1]: Chapter 6, Chapter 7, Chapter 8 (Sections 8.5--8.8).

[3]: Chapter 1 (for a quick review/description of expectation etc.)

Forwards and futures, marking to market, value of a forward/futures contract, replicating portfolios, futures on assets with known income or dividend yield, currency futures, hedging (short, long, cross, rolling), optimal hedge ratio, hedging with stock index futures, interest rate futures, swaps. Lognormal distribution, Lognormal model / Geometric Brownian Motion for stock prices, Binomial Tree model for stock prices, parameter estimation, comparison of the models. Options, Types of options: put / call, European / American, pay off of an option, factors affecting option prices, put call parity.

[1]: Chapter 10 (except 10.11, 10.12), Chapter 11 (except 11.2 and 11.8)

[2]: Chapter 3, Chapter 5, Chapter 6, Chapter 7 (except 7.10 and 7.11), Chapter 8, Chapter 9

[3]: Chapter 3

REFERENCES:

1. **David G. Luenberger**, *Investment Science*, Oxford University Press, Delhi, 1998.
2. **John C. Hull**, *Options, Futures and Other Derivatives* (6th Edition), Prentice-Hall India, Indian reprint, 2006.
3. **Sheldon Ross**, *An Elementary Introduction to Mathematical Finance* (2nd Edition), Cambridge University Press, USA, 2003.

DSE-2(ii) Discrete Mathematics

Total Marks: 100
Theory: 75
Internal Assessment: 25
5 Lectures, 1 Tutorial (per week per student)

Definition, examples and basic properties of ordered sets, maps between ordered sets, duality principle, lattices as ordered sets, lattices as algebraic structures, sublattices, products and homomorphisms.

[1]: Chapter 1 (till the end of 1.18), Chapter 2 (Sections 2.1-2.13), Chapter 5 (Sections 5.1-5.11).

[3]: Chapter 1 (Section 1).

Definition, examples and properties of modular and distributive lattices, Boolean algebras, Boolean polynomials, minimal forms of Boolean polynomials, Quinn-McCluskey method, Karnaugh diagrams, switching circuits and applications of switching circuits.

[1]: Chapter 6.

[3]: Chapter 1 (Sections 3-4, 6), Chapter 2 (Sections 7-8).

Definition, examples and basic properties of graphs, pseudographs, complete graphs, bipartite graphs, isomorphism of graphs, paths and circuits, Eulerian circuits, Hamiltonian cycles, the adjacency matrix, weighted graph, travelling salesman's problem, shortest path, Dijkstra's algorithm, Floyd-Warshall algorithm.

[2]: Chapter 9, Chapter 10.

REFERENCES:

1. **B A. Davey** and **H. A. Priestley**, *Introduction to Lattices and Order,* Cambridge University Press, Cambridge, 1990.
2. **Edgar G. Goodaire** and **Michael M. Parmenter**, *Discrete Mathematics with Graph Theory* (2nd Edition), Pearson Education (Singapore) Pte. Ltd., Indian Reprint 2003.
3. **Rudolf Lidl** and **Günter Pilz**, *Applied Abstract Algebra* (2nd Edition), Undergraduate Texts in Mathematics, Springer (SIE), Indian reprint, 2004.

DSE-2(iii) CRYPTOGRAPHY AND NETWORK SECURITY

Total Marks: 100
Theory: 75
Internal Assessment: 25
5 Lectures, 1 Tutorial (per week per student)

Definition of a cryptosystem, Symmetric cipher model, Classical encryption techniques-Substitution and transposition ciphers, caesar cipher, Playfair cipher. Block cipher Principles, Shannon theory of diffusion and confusion, Data encryption standard (DES).

[1] 2.1-2.3, 3.1, 3.2, 3.3.

Polynomial and modular arithmetic, Introduction to finite field of the form GF(p) and GF(2^n), Fermat theorem and Euler's theorem(statement only), Chinese Remainder theorem, Discrete logarithm.

[1] 4.2, 4.3, 4.5, 4.6, 4.7, 8.2, 8.4, 8.5

Advanced Encryption Standard(AES), Stream ciphers . Introduction to public key cryptography, RSA algorithm and security of RSA, Introduction to elliptic curve cryptography.

[1] 5.2-5.5(tables 5.5, 5.6 excluded),7.4, 9.1, 9.2, 10.3, 10.4

Information/Computer Security: Basic security objectives, security attacks, security services, Network security model,

[1]1.1, 1.3, 1.4, 1.6

Cryptographic Hash functions, Secure Hash algorithm, SHA-3.

[1] 11.1, 11.5, 11.6

Digital signature, Elgamal signature, Digital signature standards, Digital signature algorithm

[1] 13.1, 13.2, 13.4

E-mail security: Pretty Good Privacy (PGP)

[1] 18.1 Page 592-596(Confidentiality excluded)

REFERENCE:

[1] William Stallings, "Cryptography and Network Security", Principles and Practise, Fifth Edition, Pearson Education, 2012.

SUGGESTED READING:

[1] Douglas R. Stinson, "Cryptography theory and practice", CRC Press, Third edition, 2005.

DSE-3: Any one of the following (at least two shall be offered by the college):

DSE-3(i) Probability Theory and Statistics

Total marks: 100
Theory: 75
Internal Assessment: 25
5 Lectures, 1 Tutorial (per week per student)

Sample space, probability axioms, real random variables (discrete and continuous), cumulative distribution function, probability mass/density functions, mathematical expectation, moments, moment generating function, characteristic function, discrete distributions: uniform, binomial, Poisson, geometric, negative binomial, continuous distributions: uniform, normal, exponential.
[1]: Chapter 1 (Sections 1.1, 1.3, 1.5-1.9).
[2]: Chapter 5 (Sections 5.1-5.5, 5.7), Chapter 6 (Sections 6.2-6.3, 6.5-6.6).

Joint cumulative distribution function and its properties, joint probability density functions, marginal and conditional distributions, expectation of function of two random variables, conditional expectations, independent random variables, bivariate normal distribution, correlation coefficient, joint moment generating function (jmgf) and calculation of covariance (from jmgf), linear regression for two variables.

[1]: Chapter 2 (Sections 2.1, 2.3-2.5).

[2]: Chapter 4 (Exercise 4.47), Chapter 6 (Section 6.7), Chapter 14 (Sections 14.1, 14.2).

Chebyshev's inequality, statement and interpretation of (weak) law of large numbers and strong law of large numbers, Central Limit theorem for independent and identically distributed random variables with finite variance, Markov Chains, Chapman-Kolmogorov equations, classification of states.

[2]: Chapter 4 (Section 4.4).

[3]: Chapter 2 (Section 2.7), Chapter 4 (Sections 4.1-4.3).

REFERENCES:

1. **Robert V. Hogg, Joseph W. McKean** and **Allen T. Craig**, *Introduction to Mathematical Statistics*, Pearson Education, Asia, 2007.
2. **Irwin Miller** and **Marylees Miller**, *John E. Freund's Mathematical Statistics with Applications* (7th Edition), Pearson Education, Asia, 2006.
3. **Sheldon Ross**, *Introduction to Probability Models* (9th Edition), Academic Press, Indian Reprint, 2007.

SUGGESTED READING:

1. **Alexander M**. **Mood**, **Franklin** A. **Graybill** and **Duane C. Boes**, *Introduction to the Theory of Statistics*, (3_{rd} Edition), Tata McGraw- Hill, Reprint 2007

DSE-3(ii) Mechanics

Total Marks: 100
Theory: 75
Internal Assessment: 25
5 Lectures, 1 Tutorial (per week per student)

Moment of a force about a point and an axis, couple and couple moment, Moment of a couple about a line, resultant of a force system, distributed force system, free body diagram, free body involving interior sections, general equations of equilibrium, two point equivalent loading, problems arising from structures, static indeterminacy.
[1]: Chapter 3, Chapter 4, Chapter 5.
Laws of Coulomb friction, application to simple and complex surface contact friction problems, transmission of power through belts, screw jack, wedge, first moment of an area and the centroid, other centers, Theorem of Pappus-Guldinus, second moments and the product of area of a plane area, transfer theorems, relation between second moments and products of area, polar moment of area, principal axes.
[1]: Chapter 6 (Sections 6.1-6.7), Chapter 7

Conservative force field, conservation for mechanical energy, work energy equation, kinetic energy and work kinetic energy expression based on center of mass, moment of momentum equation for a single particle and a system of particles, translation and rotation of rigid bodies, Chasles' theorem, general relationship between time derivatives of a vector for different references, relationship between velocities of a particle for different references, acceleration of particle for different references.

[1]: Chapter 11, Chapter 12 (Sections 12.5-12.6), Chapter 13.

REFERENCES:

1. I.**H. Shames** and **G. Krishna Mohan Rao**, *Engineering Mechanics: Statics and Dynamics* (4th Edition), Dorling Kindersley (India) Pvt. Ltd. (Pearson Education), Delhi, 2009.
2. **R.C. Hibbeler** and **Ashok Gupta**, *Engineering Mechanics: Statics and Dynamics* (11th Edition), Dorling Kindersley (India) Pvt. Ltd. (Pearson Education), Delhi.

DSE-3(iii) Bio-Mathematics

Total Marks: 100

Theory: 75

Internal Assessment: 25

5 Lectures, 1 Tutorial (per week per student)

Population growth, Administration of drugs, Cell division. Modelling Biological Phenomena: Heart beat, Blood Flow, Nerve Impulse transmission, Chemical Reactions, Predator-prey models. Stability and oscillations: Epidemics, the phase plane, Local Stability, Stability, Limit Cycles, Forced oscillations, Computing trajectories. Mathematics of Heart Physiology: The local model, The Threshold effect, The phase plane analysis and the heart beat model, Physiological considerations of the heart beat model, A model of the cardiac pace-maker. Mathematics of Nerve Impulse transmission: Excitability and repetitive firing, travelling waves. Bifurcation and chaos: Bifurcation, Bifurcation of a limit cycle, Discrete bifurcation, Chaos, Stability, The Poincare plane, Computer programs for Iteration Schemes.

References: Relevant sections of chapters 1, 3, 4, 5, 6, 7 and 13 of [4]

Mathematics of imaging of the Brain: Modelling of computerized tomography (CT, Magnetic resonance Imaging (MRI), Positron emission Tomography (PET), Single Photon Emission Computerized Tomography(SPECT), Discrete analogues and Numerical Implementation. Networks in Biological Sciences: Dynamics of Small world networks, scale-free networks, complex networks, cellular automata.

References: Relevant parts of [2] and [3]

Modelling Molecular Evolution: Matrix models of base substitutions for DNA sequences, The Jukes-Cantor Model, the Kimura Models, Phylogenetic distances. Constructing Phylogenetic trees: Unweighted pair-group method with arithmetic means (UPGMA), Neighbour- Joining Method, Maximum Likelihood approaches. Genetics: Mendelian Genetics, Probability distributions in Genetics, Linked genes and Genetic Mapping, Statistical Methods and Prediction techniques.

References: Relevant sections of Chapters 4, 5 and 6 of [1] and chapters 3, 4, 6 and 8 of [5].

Recommended Books:

1. Elizabeth S. Allman and John a. Rhodes, Mathematical Models in Biology, Cambridge University Press, 2004.
2. C. Epstein, The Mathematics of Medical Imaging, Prentice Hall, 2003 (copyright Pearson Education, 2005).
3. S. Helgason, The Radon transform, Second Edition, Birkhauser, 1997.
4. D. S. Jones and B. D. Sleeman, Differential Equations and Mathematical Biology, Cahapman & Hall, CRC Press, London, UK, 2003.
5. James Keener and James Sneyd, Mathematical Physiology, Springer Verlag, 1998, Corrected 2nd printing, 2001.

DSE-4: Any one of the following (at least two shall be offered by the college):

DSE-4(i) Number Theory

Total Marks: 100
Theory: 75
Internal Assessment: 25
5 Lectures, 1 Tutorial (per week per student)

Linear Diophantine equation, prime counting function, statement of prime number theorem, Goldbach conjecture, linear congruences, complete set of residues, Chinese remainder theorem, Fermat's little theorem, Wilson's theorem.

References:

[1]: Chapter 2 (Section 2.5), Chapters 3 (Section 3.3), Chapter 4 (Sections 4.2 and 4.4), Chapter 5 (Section 5.2 excluding pseudoprimes, Section 5.3).

[2]: Chapter 3 (Section 3.2).

Number theoretic functions, sum and number of divisors, totally multiplicative functions, definition and properties of the Dirichlet product, the Möbius inversion formula, the greatest integer function, Euler's phi-function, Euler's theorem, reduced set of residues, some properties of Euler's phi-function.

References:

[1]: Chapter 6 (Sections 6.1-6.3), Chapter 7.

[2]: Chapter 5 (Section 5.2 (Definition 5.5-Theorem 5.40), Section 5.3 (Theorem 5.15-Theorem 5.17, Theorem 5.19)).

Order of an integer modulo n, primitive roots for primes, composite numbers having primitive roots, Euler's criterion, the Legendre symbol and its properties, quadratic reciprocity, quadratic congruences with composite moduli. Public key encryption, RSA encryption and decryption, the equation $x^2 + y^2 = z^2$, Fermat's Last Theorem.

Reference:

[1]: Chapters 8 (Sections 8.1-8.3), Chapter 9, Chapter 10 (Section 10.1), Chapter 12.

REFERENCES:

1. **David M. Burton**, *Elementary Number Theory* (6th Edition), Tata McGraw-Hill Edition, Indian reprint, 2007.
2. **Neville Robinns,** *Beginning Number Theory* (2nd Edition), Narosa Publishing House Pvt. Limited, Delhi, 2007.

DSE-4 (ii)   Linear Programming and Theory of Games

Total Marks: 100
Theory: 75
Internal Assessment: 25
5 Lectures, 1 Tutorial (per week per student)

Introduction to linear programming problem, Theory of simplex method, optimality and unboundedness, the simplex algorithm, simplex method in tableau format, introduction to artificial variables, two-phase method, Big-M method and their comparison.
[1]: Chapter 3 (Sections 3.2-3.3, 3.5-3.8), Chapter 4 (Sections 4.1-4.4).

Duality, formulation of the dual problem, primal-dual relationships, economic interpretation of the dual.
[1]: Chapter 6 (Sections 6.1- 6.3).

Transportation problem and its mathematical formulation, northwest-corner method least cost method and Vogel approximation method for determination of starting basic solution, algorithm for solving transportation problem, assignment problem and its mathematical formulation, Hungarian method for solving assignment problem.
[3]: Chapter 5 (Sections 5.1, 5.3-5.4).

Game theory: formulation of two person zero sum games, solving two person zero sum games, games with mixed strategies, graphical solution procedure, linear programming solution of games.
[2]: Chapter 14.

REFERENCES:

1. **Mokhtar S. Bazaraa**, **John J. Jarvis** and **Hanif D. Sherali**, *Linear Programming and Network Flows* (2nd edition), John Wiley and Sons, India, 2004.
2. **F. S. Hillier** and **G. J. Lieberman**, *Introduction to Operations Research- Concepts and Cases* (9th Edition), Tata McGraw Hill, 2010.
3. **Hamdy A. Taha**, *Operations Research, An Introduction* (9th edition), Prentice-Hall, 2010.

SUGGESTED READING:

1. G. Hadley, *Linear Programming*, Narosa Publishing House, New Delhi, 2002.

DSE-4(iii) Applications of Algebra

Total Marks: 100
Theory: 75
Internal Assessment: 25
5 Lectures, 1 Tutorial (per week per student)

Balanced incomplete block designs (BIBD): definitions and results, incidence matrix of a BIBD, construction of BIBD from difference sets, construction of BIBD using quadratic residues, difference set families, construction of BIBD from finite fields.

[2]: Chapter 2 (Sections 2.1-2.4,2.6).

Coding Theory: introduction to error correcting codes, linear cods, generator and parity check matrices, minimum distance, Hamming Codes, decoding and cyclic codes.

[2]: Chapter 4 (Sections 4.1-4.3.17).

Symmetry groups and color patterns: review of permutation groups, groups of symmetry and action of a group on a set; colouring and colouring patterns, Polya theorem and pattern inventory, generating functions for non-isomorphic graphs.

[2]: Chapter 5.

Application of linear transformations: Fibonacci numbers, incidence models, and differential equations. Lease squares methods: Approximate solutions of system of linear equations, approximate inverse of an $m^{x}n$ matrix, solving a matrix equation using its normal equation, finding functions that approximate data. Linear algorithms: LDU factorization, the row reduction algorithm and its inverse, backward and forward substitution, approximate substitution, approximate inverse and projection algorithms.

[1]: Chapter 9-11.

Reference:

2. I.N. Herstein and D.J. Winter, *Primer on Linear Algebra,* Macmillan Publishing Company, New York, 1990.

3. S.R. Nagpaul and S.K. Jain, *Topics in Applied Abstract Algebra,* Thomson Brooks and Cole, Belmont, 2005.

SEC-1 LaTeX and HTML

2 Lectures + 2 Practical per week

Elements of LaTeX; Hands-on-training of LaTex; graphics in LaTeX; PSTricks; Beamer presentation; HTML, creating simple web pages, images and links, design of web pages.

[1] Chapter 9-11, 15

Practical

Six practical should be done by each student. The teacher can assign practical from the exercises from [1].

References:

[1] Martin J. Erickson and Donald Bindner, A Student's Guide to the Study, Practice, and Tools of Modern Mathematics, CRC Press, Boca Raton, FL, 2011.

[2] L. Lamport, LATEX: A Document Preparation System, User's Guide and Reference Manual. Addison-Wesley, New York, second edition, 1994.

SEC-2 Computer Algebra Systems and Related Softwares

2 Lectures + 2 Practical per week

Use of Mathematica, Maple, and Maxima as calculator, in computing functions, in making graphs; MATLAB/Octave for exploring linear algebra and to plot curve and surfaces; the statistical software R: R as a calculator, explore data and relations, testing hypotheses, generate table values and simulate data, plotting.

[1] Chapter 12-14

Practical

Six practical should be done by each student. The teacher can assign practical from the exercises from [1].

References:

[1] Martin J. Erickson and Donald Bindner, A Student's Guide to the Study, Practice, and Tools of Modern Mathematics, CRC Press, Boca Raton, FL, 2011.

UNIVERSITY OF DELHI

BACHELOR OF SCIENCE (HONS.) IN MATHEMATICS

(B.Sc. (Hons.) Mathematics)

Learning Outcomes based Curriculum Framework (LOCF)

2019

Table of Contents

1. Introduction

The current focus in higher education is to shift from teacher-centric approach to learner-centric approach. For this as one of the aims, UGC has introduced the learning outcomes-based curriculum framework for undergraduate education. The learning outcomes-based curriculum framework for B.Sc. (Hons.) Mathematics is prepared keeping this in view. The framework is expected to provide a student with knowledge and skills in mathematics along with generic and transferable skills in other areas that help in personal development, employment and higher education in the global world. The programme-learning outcomes and course learning outcomes have been clearly specified to help prospective students, parents and employers understand the nature and extent of the degree programme; to maintain national and international standards, and to help in student mobility.

2. Learning Outcomes based approach to Curriculum Planning

The learning outcomes-based curriculum framework for B.Sc. (Hons.) Mathematics is based on the expected learning outcomes and graduate attributes that a graduate in mathematics is expected to attain. The curriculum for B.Sc. (Hons.) Mathematics is prepared keeping in mind the needs and aspirations of students in mathematics as well as the evolving nature of mathematics as a subject. The course learning outcomes and the programme learning outcomes specify the knowledge, understanding, skills, attitudes and values that a student completing this degree is expected to know. The qualification of B.Sc. (Hons.) Mathematics is awarded to a student who can demonstrating the attainment of these outcomes.

2.1 Nature and extent of the B.Sc. (Hons.) Mathematics

Mathematics is usually described as the abstract science of number, quantity and space along with their operations. The scope of Mathematics is very broad and it has a wide range of applications in natural sciences, engineering, economics and social sciences. B.Sc. (Hons.) Mathematics Programme aims at developing the ability to think critically, logically and analytically and hence use mathematical reasoning in everyday life. Pursuing a degree in mathematics will introduce the students to a number of interesting and useful ideas in preparations for a number of mathematics careers in education, research, government sector, business sector and industry.

The B.Sc. (Hons.) Mathematics programme covers the full range of mathematics, from classical Calculus to Modern Cryptography, Information Theory, and Network Security. The course lays a structured foundation of Calculus, Real & Complex analysis, Abstract Algebra, Differential Equations (including Mathematical Modelling), Number Theory, Graph Theory, and C++ Programming exclusively for Mathematics.

An exceptionally broad range of topics covering Pure & Applied Mathematics: Linear Algebra, metric Spaces, Statistics, Linear Programming, Numerical Analysis, Mathematicl Fi nance, Coding Theory, Mechanics and Biomathematics cater to varied interests and ambitions. Also hand on sessions in Computer Lab using various Computer Algebra Systems (CAS) softwares such as Mathematica, MATLAB, Maxima, **R** to have a deep conceptual understanding of the above tools are carried out to widen the horizon of students' self-experience. The courses like Biomathematics, Mathematical Finance etc. emphasize on the relation of mathematics to other subjects like Biology, Economics and Finance.

To broaden the interest for interconnectedness between formerly separate disciplines one can choose from the list of Generic electives for example one can opt for economics as one of the GE papers. Skill enhancement Courses enable the student acquire the skill relevant to the main subject. Choices from Discipline Specific Electives provides the student with liberty of exploring his interests within the main subject.

Of key importance is the theme of integrating mathematical and professional skills. The well-structured programme empowers the student with the skills and knowledge leading to enhanced career opportunities in industry, commerce, education, finance and research.

2.2 Aims of Bachelor's degree programme in Mathematics

The overall aims of B.Sc.(Hons) Mathematics Programme are to:

- inculcate strong interest in learning mathematics.
- evolve broad and balanced knowledge and understanding of definitions, key concepts, principles and theorems in Mathematics
- enable learners/students to apply the knowledge and skills acquired by them during the programme to solve specific theoretical and applied problems in mathematics.
- develop in students the ability to apply relevant tools developed in mathematical theory to handle issues and problems in social and natural sciences.
- provide students with sufficient knowledge and skills that enable them to undertake further studies in mathematics and related disciplines
- enable students to develop a range of generic skills which will be helpful in wage-employment, self-employment and entrepreneurship.

3. Graduate Attributes in Mathematics

Some of the graduate attributes in mathematics are listed below:

3.1 Disciplinary knowledge: Capability of demonstrating comprehensive knowledge of basic concepts and ideas in mathematics and its subfields, and its applications to other disciplines.

3.2 Communications skills: Ability to communicate various concepts of mathematics in effective and coherent manner both in writing and orally, ability to present the complex mathematical ideas in clear, precise and confident way, ability to explain the development and importance of mathematics and ability to express thoughts and views in mathematically or logically correct statements.

3.3 Critical thinking and analytical reasoning: Ability to apply critical thinking in understanding the concepts in mathematics and allied areas; identify relevant assumptions, hypothesis, implications or conclusions; formulate mathematically correct arguments; ability to analyse and generalise specific arguments or empirical data to get broader concepts.

3.4 Problem solving: Capacity to use the gained knowledge to solve different kinds of non-familiar problems and apply the learning to real world situations; Capability to solve problems in computer graphics using concepts of linear algebra; Capability to apply the knowledge gained in differential equations to solve specific problems or models in operations research, physics, chemistry, electronics, medicine, economics, finance etc.

3.5 Research-related skills: Capability to ask and inquire about relevant/appropriate questions, ability to define problems, formulate hypotheses, test hypotheses, formulate mathematical arguments and proofs, draw conclusions; ability to write clearly the results obtained.

3.6 Information/digital literacy: Capacity to use ICT tools in solving problems or gaining knowledge; capacity to use appropriate softwares and programming skills to solve problems in mathematics,

3.7 Self-directed learning: Ability to work independently, ability to search relevant resources and e-content for self-learning and enhancing knowledge in mathematics.

3.8 Moral and ethical awareness/reasoning: Ability to identify unethical behaviour such as fabrication or misrepresentation of data, committing plagiarism, infringement of intellectual property rights.

3.9 Lifelong learning: Ability to acquire knowledge and skills through self-learning that helps in personal development and skill development suitable for changing demands of work place.

4. Qualification descriptors for B.Sc. (Hons.) Mathematics

Students who choose B.Sc. (Hons.) Mathematics Programme, develop the ability to think critically, logically and analytically and hence use mathematical reasoning in everyday life.

Pursuing a degree in mathematics will introduce the students to a number of interesting and useful ideas in preparations for a number of mathematics careers in education, research, government sector, business sector and industry.

The programme covers the full range of mathematics, from classical Calculus to Modern Cryptography, Information Theory, and Network Security. The course lays a structured foundation of Calculus, Real & Complex analysis, Abstract Algebra, Differential Equations (including Mathematical Modeling), Number Theory, Graph Theory, and C++ Programming exclusively for Mathematics.

An exceptionally broad range of topics covering Pure & Applied Mathematics: Linear Algebra, Metric Spaces, Statistics, Linear Programming, Numerical Analysis, Mathematical Finance, Coding Theory, Mechanics and Biomathematics cater to varied interests and ambitions. Also hand on sessions in Computer Lab using various Computer Algebra Systems (CAS) softwares such as Mathematica, MATLAB, Maxima, **R** to have a deep conceptual understanding of the above tools are carried out to widen the horizon of students' self-experience.

To broaden the interest for interconnectedness between formerly separate disciplines one can choose from the list of Generic electives for example one can opt for economics as one of the GE papers. Skill enhancement courses enable the student acquire the skill relevant to the main subject. Choices from Discipline Specific Electives provides the student with liberty of exploring his interests within the main subject.

Of key importance is the theme of integrating mathematical and professional skills. The well-structured programme empowers the student with the skills and knowledge leading to enhanced career opportunities in industry, commerce, education, finance and research. The qualification descriptors for B.Sc. (Hons.) Mathematics may include the following:

i. demonstrate fundamental/systematic and coherent knowledge of the academic field of mathematics and its applications and links to engineering, science, technology, economics and finance; demonstrate procedural knowledge that create different professionals like teachers and researchers in mathematics, quantitative analysts, actuaries, risk managers, professionals in industry and public services.
ii. demonstrate educational skills in areas of analysis, geometry, algebra, mechanics, differential equations etc.
iii. demonstrate comprehensive knowledge about materials, including scholarly, and/or professional literature, relating to essential learning areas pertaining to the field of mathematics, and techniques and skills required for identifying mathematical problems.
iv. Apply the acquired knowledge in mathematics and transferable skills to new/unfamiliar contexts and real-life problems.
v. Demonstrate mathematics-related and transferable skills that are relevant to some of the job trades and employment opportunities.

5. Programme Learning Outcomes in B.Sc. (Hons.) Mathematics

The completion of the B.Sc. (Hons.) Mathematics Programme will enable a student to:

i) Communicate mathematics effectively by written, computational and graphic means.
ii) Create mathematical ideas from basic axioms.
iii) Gauge the hypothesis, theories, techniques and proofs provisionally.
iv) Utilize mathematics to solve theoretical and applied problems by critical understanding, analysis and synthesis.
v) Identify applications of mathematics in other disciplines and in the real-world, leading to enhancement of career prospects in a plethora of fields and research.

6. Structure of B.Sc. (Hons.) Mathematics

The B.Sc. (Hons.) Mathematics programme is a three-year, six-semesters course. A student is required to complete 148 credits for completion of the course.

		Semester	**Semester**
Part – I	First Year	Semester I: 22	Semester II: 22
Part – II	Second Year	Semester III: 28	Semester IV: 28
Part - III	Third Year	Semester V: 24	Semester VI: 24

Semester wise Details of B.Sc. (Hons.) Mathematics Course & Credit Scheme

Sem-ester	**Core Course(14)**	**Ability Enhancement Compulsory Course (AECC)(2)**	**Skill Enhancement Course (SEC)(2)**	**Discipline Specific Elective (DSE)(4)**	**Generic Elective (GE)(4)**	**Total Credits**
I	BMATH101:Calculus (including practicals) BMATH102: Algebra	(English Communication/MIL)/ Environmental Science			GE-1	
L+T/P	4 + 2 = 6; 5 + 1 = 6	4			5+1 = 6	22
II	BMATH203: Real Analysis BMATH204: Differential Equations (including practicals)	(English Communication/MIL)/ Environmental Science			GE-2	
L+T/P	5 + 1 = 6; 4 + 2 = 6	4			5+1 = 6	22

III	BMATH305: Theory of Real Functions BMATH306: Group Theory-I BMATH307: Multivariate Calculus (including practicals)		SEC-1 LaTeX and HTML		GE-3	
L+T/P	5 + 1 = 6; 5 + 1 = 6; 4 + 2 = 6		4		5 +1 = 6	28
IV	BMATH408: Partial Differential Equations (including practicals) BMATH409: Riemann Integration and Series of Functions BMATH410: Ring Theory and Linear Algebra-I		SEC-2 Computer Algebra Systems and Related Software		GE-4	
L+T/P	4 + 2 = 6; 5 + 1 = 6; 5 + 1 = 6		4		5 +1 = 6	28
V	BMATH511: Metric Spaces BMATH512: Group Theory-II			DSE-1 (including practicals) DSE-2		
L+T/P	5 + 1 = 6; 5 + 1 = 6			4 + 2 = 6; 5 + 1 = 6		24
Sem-ester	**Core Course(14)**	**Ability Enhancement Compulsory Course (AECC)(2)**	**Skill Enhancement Course (SEC)(2)**	**Discipline Specific Elective (DSE)(4)**	**Generic Elective (GE)(4)**	**Total Credits**
VI	BMATH613: Complex Analysis (including practicals) BMATH614: Ring Theory and Linear Algebra-II			DSE-3 DSE-4		
L+T/P	4 + 2 = 6; 5 + 1 = 6			5 + 1 = 6; 5 + 1 = 6		24

Total Credits = 148

Legend: L: Lecture Class; T: Tutorial Class; P: Practical Class

Note: One-hour lecture per week equals 1 Credit, 2 Hours practical class per week equals 1 credit. Practical in a group of 15-20 students in Computer Lab and Tutorial in a group of 8-12 students.

List of Discipline Specific Elective (DSE) Courses:

DSE-1 (Including Practicals): Any *one* of the following

(at least *two* shall be offered by the college)

(i) Numerical Analysis
(ii) Mathematical Modeling and Graph Theory
(iii) C++ Programming for Mathematics

DSE-2: Any *one* of the following

(at least *two* shall be offered by the college)

(i) Probability Theory and Statistics
(ii) Discrete Mathematics
(iii) Cryptography and Network Security

DSE-3: Any *one* of the following

(at least *two* shall be offered by the college)

(i) Mathematical Finance
(ii) Introduction to Information Theory and Coding
(iii) Biomathematics

DSE-4: Any *one* of the following

(at least *two* shall be offered by the college)

(i) Number Theory
(ii) Linear Programming and Applications
(iii) Mechanics

Semester-I

BMATH101: Calculus

Total Marks: 150 (Theory: 75, Internal Assessment: 25 and Practical: 50)
Workload: 4 Lectures, 4 Practicals (per week) **Credits:** 6 (4+2)
Duration: 14 Weeks (56 Hrs. Theory + 56 Hrs. Practical) **Examination:** 3 Hrs.

Course Objectives: The primary objective of this course is to introduce the basic tools of calculus and geometric properties of different conic sections which are helpful in understanding their applications in planetary motion, design of telescope and to the real-world problems. Also, to carry out the hand on sessions in computer lab to have a deep conceptual understanding of the above tools to widen the horizon of students' self-experience.

Course Learning Outcomes: This course will enable the students to:

i) Learn first and second derivative tests for relative extrema and apply the knowledge in problems in business, economics and life sciences.
ii) Sketch curves in a plane using its mathematical properties in the different coordinate systems of reference.
iii) Compute area of surfaces of revolution and the volume of solids by integrating over cross-sectional areas.
iv) Understand the calculus of vector functions and its use to develop the basic principles of planetary motion.

Unit 1: Derivatives for Graphing and Applications
The first-derivative test for relative extrema, Concavity and inflection points, Second-derivative test for relative extrema, Curve sketching using first and second derivative tests; Limits to infinity and infinite limits, Graphs with asymptotes, L'Hôpital's rule; Applications in business, economics and life sciences; Higher order derivatives, Leibniz rule.

Unit 2: Sketching and Tracing of Curves
Parametric representation of curves and tracing of parametric curves (except lines in $\mathbb{R}^3$), Polar coordinates and tracing of curves in polar coordinates; Techniques of sketching conics, Reflection properties of conics, Rotation of axes and second degree equations, Classification into conics using the discriminant.

Unit 3: Volume and Area of Surfaces
Volumes by slicing disks and method of washers, Volumes by cylindrical shells, Arc length, Arc length of parametric curves, Area of surface of revolution; Hyperbolic functions; Reduction formulae.

Unit 4: Vector Calculus and its Applications
Introduction to vector functions and their graphs, Operations with vector functions, Limits and continuity of vector functions, Differentiation and integration of vector functions; Modeling ballistics and planetary motion, Kepler's second law; Unit tangent, Normal and binormal vectors, Curvature.

References:

1. Anton, Howard, Bivens, Irl, & Davis, Stephen (2013). *Calculus* (10th ed.). John Wiley & Sons Singapore Pte. Ltd. Indian Reprint (2016) by Wiley India Pvt. Ltd. Delhi.
2. Prasad, Gorakh (2016). *Differential Calculus* (19th ed.). Pothishala Pvt. Ltd. Allahabad.
3. Strauss, Monty J., Bradley, Gerald L., & Smith, Karl J. (2007). *Calculus* (3rd ed.). Dorling Kindersley (India) Pvt. Ltd. (Pearson Education). Delhi. Indian Reprint 2011.

Additional Reading:

i. Thomas, Jr. George B., Weir, Maurice D., & Hass, Joel (2014). *Thomas' Calculus* (13th ed.). Pearson Education, Delhi. Indian Reprint 2017.

Practical / Lab work to be performed in Computer Lab.

List of the practicals to be done using Mathematica /MATLAB /Maple/Scilab/Maxima etc.

1. Plotting the graphs of the following functions:

$$ax,\ [x](\text{greatest integer function}), \sqrt{ax+b},\ |ax+b|, c \pm\ |ax+b|,$$
$$x^{\pm n}, x^{\frac{1}{n}}\ (n \in \mathbb{Z}),\ \frac{|x|}{x}, \sin\left(\frac{1}{x}\right), x\sin\left(\frac{1}{x}\right), \text{and}\ e^{\pm\frac{1}{x}}, \text{for } x \neq 0,$$
$$e^{ax+b}, \log\ (ax+b), 1/(ax+b), \sin\ (ax+b), \cos(\ ax+b),$$
$$|\sin(\ ax+b)|, |\cos(\ ax+b)|.$$

   Observe and discuss the effect of changes in the real constants *a*, *b* and *c* on the graphs.
2. Plotting the graphs of polynomial of degree 4 and 5, and their first and second derivatives, and analysis of these graphs in context of the concepts covered in Unit 1.
3. Sketching parametric curves, e.g., trochoid, cycloid, epicycloid and hypocycloid.
4. Tracing of conics in Cartesian coordinates.
5. Obtaining surface of revolution of curves.
6. Graph of hyperbolic functions.
7. Computation of limit, Differentiation, Integration and sketching of vector-valued functions.
8. Complex numbers and their representations, Operations like addition, multiplication, division, modulus. Graphical representation of polar form.
9. Find numbers between two real numbers and plotting of finite and infinite subset of $\mathbb{R}$.
10. Matrix operations: addition, multiplication, inverse, transpose; Determinant, Rank, Eigenvectors, Eigenvalues, Characteristic equation and verification of the Cayley–Hamilton theorem, Solving the systems of linear equations.

Teaching Plan (Theory of BMATH101: Calculus):

Week 1: The first-derivative test for relative extrema, Concavity and inflection points, Second-derivative test for relative extrema, Curve sketching using first and second derivative tests.

[3] Chapter 4 (Section 4.3).

Week 2: Limits to infinity and infinite limits, Graphs with asymptotes, Vertical tangents and cusps, L'Hôpital's rule.

[3] Chapter 4 (Sections 4.4 and 4.5).

Week 3: Applications of derivatives in business, economics and life sciences. Higher order derivatives and Leibniz rule for higher order derivatives for the product of two functions.

[3] Chapter 4 (Section 4.7).

[2] Chapter 5 (Sections 5.1, 5.2 and 5.4).

Week 4: Parametric representation of curves and tracing of parametric curves (except lines in $\mathbb{R}^3$), Polar coordinates and the relationship between Cartesian and polar coordinates.

[3] Chapter 9 [Section 9.4 (Pages 471 to 475)].

[1] Chapter 10 (Sections 10.1, and 10.2 up to Example 2, Page 707).

Weeks 5 and 6: Tracing of curves in polar coordinates. Techniques of sketching conics**:** parabola, ellipse and hyperbola.

[1] Sections 10.2 (Pages 707 to 717), and 10.4 up to Example 10 Page 742)].

Week 7: Reflection properties of conics, Rotation of axes, Second degree equations and their classification into conics using the discriminant.

[1] Sections 10.4 (Pages 742 to 744) and 10.5.

Weeks 8 and 9: Volumes by slicing disks and method of washers, Volumes by cylindrical shells, Arc length, Arc length of parametric curves.

[1] Chapter 5 (Sections 5.2, 5.3 and 5.4).

Week 10: Area of surface of revolution; Hyperbolic functions.

[1] Sections 5.5 and 6.8.

Week 11: Reduction formulae, and to obtain the iterative formulae for the integrals of the form**:**$\int \sin^n x\, dx$, $\int \cos^n x\, dx$, $\int \tan^n x\, dx$, $\int \sec^n x\, dx$ and $\int \sin^m x \cos^n x\, dx$.

[1] Chapter 7 [Sections 7.2 and 7.3 (Pages 497 to 503)].

Week 12: Introduction to vector functions and their graphs, Operations with vector functions, Limits and continuity of vector functions, Differentiation and tangent vectors.

[3] Chapter 10 (Sections 10.1 and 10.2 up to Page 504).

Week 13: Properties of vector derivatives and integration of vector functions; Modeling ballistics and planetary motion, Kepler's second law.

[3] Chapter 10 [Sections 10.2 (Pages 505 to 511) and 10.3].

Week 14: Unit tangent, Normal and binormal vectors, Curvature.

[1] Sections 12.4 and 12.5.

Facilitating the Achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
1.	Learn first and second derivative tests for relative extrema and apply the knowledge in problems in business, economics and life sciences.	(i) Each topic to be explained with illustrations. (ii) Students to be encouraged to discover the relevant concepts. (iii) Students be given homework/assignments. (iv) Discuss and solve the theoretical and practical problems in the class. (v) Students to be encouraged to apply concepts to real world problems.	• Presentations and class discussions. • Assignments and class tests. • Student presentations. • Mid-term examinations. • Practical and viva-voce examinations. • End-term examinations.
2.	Sketch curves in a plane using its mathematical properties in the different coordinate systems of reference.		
3.	Compute area of surfaces of revolution and the volume of solids by integrating over cross-sectional areas.		
4.	Understand the calculus of vector functions and its use to develop the basic principles of planetary motion.		

Keywords: Concavity, Extrema, Inflection point, Hyperbolic functions, Leibniz rule, L'Hôpital's rule, Polar and parametric coordinates, Vector functions.

BMATH102: Algebra

Total Marks: 100 (Theory: 75, Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: The primary objective of this course is to introduce the basic tools of theory of equations, complex numbers, number theory and matrices to understand their connection with the real-world problems. Perform matrix algebra with applications to computer graphics.

Course Learning Outcomes: This course will enable the students to:

i) Employ De Moivre's theorem in a number of applications to solve numerical problems.
ii) Learn about equivalent classes and cardinality of a set.
iii) Use modular arithmetic and basic properties of congruences.
iv) Recognize consistent and inconsistent systems of linear equations by the row echelon form of the augmented matrix.
v) Find eigenvalues and corresponding eigenvectors for a square matrix.

Unit 1: Theory of Equations and Complex Numbers
Polynomials, The remainder and factor theorem, Synthetic division, Factored form of a polynomial, Fundamental theorem of algebra, Relations between the roots and the coefficients of polynomial equations, Theorems on imaginary, integral and rational roots; Polar representation of complex numbers, De Moivre's theorem for integer and rational indices and their applications. The nth roots of unity.

Unit 2: Equivalence Relations and Functions
Equivalence relations, Functions, Composition of functions, Invertibility and inverse of functions, One-to-one correspondence and the cardinality of a set.

Unit 3: Basic Number Theory
Well ordering principle, The division algorithm in $\mathbb{Z}$, Divisibility and the Euclidean algorithm, Fundamental theorem of arithmetic, Modular arithmetic and basic properties of congruences; Principle of mathematical induction.

Unit 4: Row Echelon Form of Matrices and Applications
Systems of linear equations, Row reduction and echelon forms, Vector equations, The matrix equation $A\mathbf{x} = b$, Solution sets of linear systems, The inverse of a matrix; Subspaces, Linear independence, Basis and dimension, The rank of a matrix and applications; Introduction to linear transformations, The matrix of a linear transformation; Applications to computer graphics, Eigenvalues and eigenvectors, The characteristic equation and Cayley–Hamilton theorem.

References:

1. Andreescu, Titu & Andrica Dorin. (2014). *Complex Numbers from A to...Z.* (2nd ed.). Birkhäuser.

2. Dickson, Leonard Eugene (2009). *First Course in the Theory of Equations*. The Project Gutenberg EBook (http://www.gutenberg.org/ebooks/29785)
3. Goodaire, Edgar G., & Parmenter, Michael M. (2005). *Discrete Mathematics with Graph Theory* (3rd ed.). Pearson Education Pvt. Ltd. Indian Reprint 2015.
4. Kolman, Bernard, & Hill, David R. (2001). *Introductory Linear Algebra with Applications* (7th ed.). Pearson Education, Delhi. First Indian Reprint 2003.
5. Lay, David C., Lay, Steven R., & McDonald, Judi J. (2016). *Linear Algebra and its Applications* (5th ed.). Pearson Education.

Additional Readings:

i. Andrilli, Stephen, & Hecker, David (2016). *Elementary Linear Algebr*a (5th ed.). Academic Press, Elsevier India Private Limited.
ii. Burton, David M. (2012). *Elementary Number Theory* (7th ed.). McGraw-Hill Education Pvt. Ltd. Indian Reprint.

Teaching Plan (BMATH102: Algebra):

Weeks 1 and 2: Polynomials, The remainder and factor theorem, Synthetic division, Factored form of a polynomial, Fundamental theorem of algebra, Relations between the roots and the coefficients of polynomial equations, Theorems on imaginary, integral and rational roots.

[2] Chapter II (Sections 12 to 16, 19 to 21, 24 and 27, Statement of the Fundamental theorem of algebra).

Weeks 3 and 4: Polar representation of complex numbers, De Moivre's theorem for integer and rational indices and their applications, The *n*th roots of unity.

[1] Chapter 2 [Section 2.1(2.1.1 to 2.1.3), Section 2.2 (2.2.1, 2.2.2 (up to Page 45, without propositions), 2.2.3].

Weeks 5 and 6. Equivalence relations, Functions, Composition of functions, Invertibility and inverse of functions, One-to-one correspondence and the cardinality of a set.

[3] Chapter 2 (Section 2.4 (2.4.1 to 2.4.4)), and Chapter 3.

Weeks 7 and 8: Well ordering principle, The division algorithm in $\mathbb{Z}$, Divisibility and the Euclidean algorithm, Modular arithmetic and basic properties of congruences, Statements of the fundamental theorem of arithmetic and principle of mathematical induction.

[3] Chapter 4 [Sections 4.1 (4.1.2,4.1.5,4.1.6), 4.2 (4.2.1 to 4.2.11, up to problem 11), 4.3 (4.3.7 to 4.3.9), 4.4 (4.4.1 to 4.4.8)], and Chapter 5 (Section 5.1.1).

Weeks 9 and 10: Systems of linear equations, Row reduction and echelon forms, Vector equations, The matrix equation $A\mathbf{x} = b$, Solution sets of linear systems, The inverse of a matrix.

[5] Chapter 1 (Sections 1.1 to 1.5) and Chapter 2 (Section 2.2).

Week 11 and 12: Subspaces, Linear independence, Basis and dimension, The rank of a matrix and applications.

[4] Chapter 6 (Sections 6.2, 6.3, 6.4, and 6.6).

Weeks 13: Introduction to linear transformations, Matrix of a linear transformation; Applications to computer graphics.

[5] Chapter 1 (Sections 1.8 and 1.9), and Chapter 2 (Section 2.7).

Week 14: Eigenvalues and eigenvectors, The characteristic equation and Cayley–Hamilton theorem.

[5] Chapter 5 (Sections 5.1 and 5.2, Supplementary Exercises 5 and 7, Page 328).

Facilitating the Achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
1.	Employ De Moivre's theorem in a number of applications to solve	(i) Each topic to be explained with examples.	• Student

	numerical problems.	(ii) Students to be involved in discussions and encouraged to ask questions. (iii) Students to be given homework/assignments. (iv) Students to be encouraged to give short presentations.	presentations. • Participation in discussions. • Assignments and class tests. • Mid-term examinations. • End-term examinations.
2.	Learn about equivalent classes and cardinality of a set.		
3.	Use modular arithmetic and basic properties of congruences.		
4.	Recognize consistent and inconsistent systems of linear equations by the row echelon form of the augmented matrix. Find eigenvalues and corresponding eigenvectors for a square matrix.		

Keywords: Cardinality of a set, Cayley–Hamilton theorem, De Moivre's theorem, Eigenvalues and eigenvectors, Equivalence relations, Modular arithmetic, Row echelon form, The Fundamental theorem of algebra.

Semester-II

BMATH203: Real Analysis

Total Marks: 100 (Theory: 75, Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: The course will develop a deep and rigorous understanding of real line $\mathbb{R}$. and of defining terms to prove the results about convergence and divergence of sequences and series of real numbers. These concepts have wide range of applications in real life scenario.

Course Learning Outcomes: This course will enable the students to:

i) Understand many properties of the real line $\mathbb{R}$, including completeness and Archimedean properties.
ii) Learn to define sequences in terms of functions from $\mathbb{N}$ to a subset of $\mathbb{R}$.
iii) Recognize bounded, convergent, divergent, Cauchy and monotonic sequences and to calculate their limit superior, limit inferior, and the limit of a bounded sequence.
iv) Apply the ratio, root, alternating series and limit comparison tests for convergence and absolute convergence of an infinite series of real numbers.

Unit 1: Real Number System $\mathbb{R}$
Algebraic and order properties of $\mathbb{R}$, Absolute value of a real number; Bounded above and bounded below sets, Supremum and infimum of a nonempty subset of $\mathbb{R}$.

Unit 2: Properties of $\mathbb{R}$
The completeness property of $\mathbb{R}$, Archimedean property, Density of rational numbers in $\mathbb{R}$; Definition and types of intervals, Nested intervals property; Neighborhood of a point in $\mathbb{R}$, Open and closed sets in $\mathbb{R}$.

Unit 3: Sequences in $\mathbb{R}$
Convergent sequence, Limit of a sequence, Bounded sequence, Limit theorems, Monotone sequences, Monotone convergence theorem, Subsequences, Bolzano−Weierstrass theorem for sequences, Limit superior and limit inferior for bounded sequence, Cauchy sequence, Cauchy's convergence criterion.

Unit 4: Infinite Series
Convergence and divergence of infinite series of real numbers, Necessary condition for convergence, Cauchy criterion for convergence; Tests for convergence of positive term series**:** Integral test, Basic comparison test, Limit comparison test, D'Alembert's ratio test, Cauchy's nth root test; Alternating series, Leibniz test, Absolute and conditional convergence.

References:

1. Bartle, Robert G., & Sherbert, Donald R. (2015). *Introduction to Real Analysis* (4th ed.). Wiley India Edition. New Delhi.
2. Bilodeau, Gerald G., Thie, Paul R., & Keough, G. E. (2010). *An Introduction to Analysis* (2nd ed.). Jones & Bartlett India Pvt. Ltd. Student Edition. Reprinted 2015.

3. Denlinger, Charles G. (2011). *Elements of Real Analysis*. Jones & Bartlett India Pvt. Ltd. Student Edition. Reprinted 2015.

Additional Readings:

i. Ross, Kenneth A. (2013). *Elementary Analysis*: *The Theory of Calculus* (2nd ed.). Undergraduate Texts in Mathematics, Springer. Indian Reprint.
ii. Thomson, Brian S., Bruckner, Andrew. M., & Bruckner, Judith B. (2001). *Elementary Real Analysis.* Prentice Hall.

Teaching Plan (BMATH203: Real Analysis):

Weeks 1 and 2: Algebraic and order properties of ℝ. Absolute value of a real number; Bounded above and bounded below sets, Supremum and infimum of a nonempty subset of ℝ.
[1] Chapter 2 [Sections 2.1, 2.2 (2.2.1 to 2.2.6) and 2.3 (2.3.1 to 2.3.5)]

Weeks 3 and 4: The completeness property of ℝ, Archimedean property, Density of rational numbers in ℝ, Definition and types of intervals, Nested intervals property; Neighborhood of a point in ℝ, Open and closed sets in ℝ.
[1] Sections 2.3 (2.3.6), 2.4 (2.4.3 to 2.4.9), and 2.5 up to Theorem 2.5.3.
[1] Chapter 11 [Section 11.1 (11.1.1 to 11.1.3)].

Weeks 5 and 6: Sequences and their limits, Bounded sequence, Limit theorems.
[1] Sections 3.1, 3.2.

Week 7: Monotone sequences, Monotone convergence theorem and applications.
[1] Section 3.3.

Week 8: Subsequences and statement of the Bolzano−Weierstrass theorem. Limit superior and limit inferior for bounded sequence of real numbers with illustrations only.
[1] Chapter 3 [Section 3.4 (3.4.1 to 3.4.12), except 3.4.4, 3.4.7, 3.4.9 and 3.4.11].

Week 9: Cauchy sequences of real numbers and Cauchy's convergence criterion.
[1] Chapter 3 [Section 3.5 (3.5.1 to 3.5.6)].

Week 10: Convergence and divergence of infinite series, Sequence of partial sums of infinite series, Necessary condition for convergence, Cauchy criterion for convergence of series.
[3] Section 8.1.

Weeks 11 and 12: Tests for convergence of positive term series**:** Integral test statement and convergence of *p*-series, Basic comparison test, Limit comparison test with applications, D'Alembert's ratio test and Cauchy's *n*th root test.
[3] Chapter 8 (Section 8.2 up to 8.2.19).

Weeks 13 and 14: Alternating series, Leibniz test, Absolute and conditional convergence.
[2] Chapter 6 (Section 6.2).

Facilitating the Achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
1. & 2.	Understand many properties of the real line ℝ including, completeness and Archimedean properties.	(i) Each topic to be explained with examples. (ii) Students to be involved in discussions and encouraged to ask questions. (iii) Students to be given homework/assignments. (iv) Students to be	• Presentations and participation in discussions. • Assignments and class tests. • Mid-term examinations. • End-term examinations.
3.	Learn to define sequences in terms of functions from ℕ to a subset of ℝ. Recognize bounded, convergent, divergent, Cauchy and monotonic sequences and to calculate their limit superior, limit inferior, and the limit of a bounded sequence.		

4.	Apply the ratio, root, alternating series and limit comparison tests for convergence and absolute convergence of an infinite series of real numbers.	encouraged to give short presentations. (v) Illustrate the concepts through CAS.	

Keywords: Archimedean property, Absolute and conditional convergence of series, Bolzano–Weierstrass theorem, Cauchy sequence, Convergent sequence, Leibniz test, Limit of a sequence, Nested intervals property, Open and closed sets in ℝ.

BMATH204: Differential Equations

Total Marks: 150 (Theory: 75, Internal Assessment: 25 and Practical: 50)
Workload: 4 Lectures, 4 Practicals (per week) **Credits:** 6 (4+2)
Duration: 14 Weeks (56 Hrs. Theory + 56 Hrs. Practical) **Examination:** 3 Hrs.

Course Objectives: The main objective of this course is to introduce the students to the exciting world of differential equations, mathematical modeling and their applications.

Course Learning Outcomes: The course will enable the students to:

i) Learn basics of differential equations and mathematical modeling.
ii) Formulate differential equations for various mathematical models.
iii) Solve first order non-linear differential equations and linear differential equations of higher order using various techniques.
iv) Apply these techniques to solve and analyze various mathematical models.

Unit 1: Differential Equations and Mathematical Modeling
Differential equations and mathematical models, Order and degree of a differential equation, Exact differential equations and integrating factors of first order differential equations, Reducible second order differential equations, Applications of first order differential equations to acceleration-velocity model, Growth and decay model.

Unit 2: Population Growth Models
Introduction to compartmental models, Lake pollution model (with case study of Lake Burley Griffin), Drug assimilation into the blood (case of a single cold pill, case of a course of cold pills, case study of alcohol in the bloodstream), Exponential growth of population, Limited growth of population, Limited growth with harvesting.

Unit 3: Second and Higher Order Differential Equations
General solution of homogeneous equation of second order, Principle of superposition for a homogeneous equation; Wronskian, its properties and applications, Linear homogeneous and non-homogeneous equations of higher order with constant coefficients, Euler's equation, Method of undetermined coefficients, Method of variation of parameters, Applications of second order differential equations to mechanical vibrations.

Unit 4: Analysis of Mathematical Models
Interacting population models, Epidemic model of influenza and its analysis, Predator-prey model and its analysis, Equilibrium points, Interpretation of the phase plane, Battle model and its analysis.

References:

1. Barnes, Belinda & Fulford, Glenn R. (2015). *Mathematical Modelling with Case Studies, Using* Maple *and* MATLAB (3rd ed.). CRC Press, Taylor & Francis Group.
2. Edwards, C. Henry, Penney, David E., & Calvis, David T. (2015). *Differential Equation and Boundary Value Problems*: *Computing and Modeling* (5th ed.). Pearson Education.
3. Ross, Shepley L. (2004). *Differential Equations* (3rd ed.). John Wiley & Sons. India

Additional Reading:

i. Ross, Clay C. (2004). *Differential Equations*: *An Introduction with Mathematica*® (2nd ed.). Springer.

Practical / Lab work to be performed in a Computer Lab:

Modeling of the following problems using Mathematica /MATLAB/Maple/Maxima/Scilab etc.

1. Plotting of second and third order respective solution family of differential equation.
2. Growth and decay model (exponential case only).
3. (i) Lake pollution model (with constant/seasonal flow and pollution concentration).
   (ii) Case of single cold pill and a course of cold pills.
   (iii) Limited growth of population (with and without harvesting).
4. (i) Predatory-prey model (basic Volterra model, with density dependence, effect of DDT, two prey one predator).
   (ii) Epidemic model of influenza (basic epidemic model, contagious for life, disease with carriers).
   (iii) Battle model (basic battle model, jungle warfare, long range weapons).
5. Plotting of recursive sequences, and study of the convergence.
6. Find a value $m \in \mathbb{N}$ that will make the following inequality holds for all $n > m$:
   $(i)\ \left|\sqrt[n]{0.5} - 1\right| < 10^{-3}$, $(ii)\ \left|\sqrt[n]{n} - 1\right| < 10^{-3}$,
   $(iii)\ (0.9)^n < 10^{-3}$, $(iv)\ \frac{2^n}{n!} < 10^{-7}$, etc.
7. Verify the Bolzano–Weierstrass theorem through plotting of sequences and hence identify convergent subsequences from the plot.
8. Study the convergence/divergence of infinite series of real numbers by plotting their sequences of partial sum.
9. Cauchy's root test by plotting *n*th roots.
10. D'Alembert's ratio test by plotting the ratio of *n*th and (*n*+1)th term of the given series of positive terms.
11. For the following sequences $\langle a_n \rangle$, given $\varepsilon = \frac{1}{2^k}, p = 10^j, k = 0,1,2, \dots; j = 1,2,3, \dots$
    Find $m \in \mathbb{N}$ such that
    $(i)\ \left|a_{m+p} - a_m\right| < \varepsilon$, $(ii)\ \left|a_{2m+p} - a_{2m}\right| < \varepsilon$,
    where a_n is given as:
    $(a)\ \frac{n+1}{n}$, $(b)\ \frac{1}{n}$, $(c)\ 1 - \frac{1}{2} + \frac{1}{3} - \cdots + \frac{(-1)^{n-1}}{n}$
    $(d)\ \frac{(-1)^n}{n}$, $(e)\ 2^{-n}n^2$, $(f)\ 1 + \frac{1}{2!} + \cdots + \frac{1}{n!}$.
12. For the following series $\sum a_n$, calculate
    $(i)\ \left|\frac{a_{n+1}}{a_n}\right|$, $(ii)\ |a_n|^{\frac{1}{n}}$, for $n = 10^j, j = 1,2,3, \dots$,
    and identify the convergent series, where a_n is given as:
    $(a)\left(\frac{1}{n}\right)^{1/n}$, $(b)\frac{1}{n}$, $(c)\ \frac{1}{n^2}$, $(d)\left(1 + \frac{1}{\sqrt{n}}\right)^{-n^{3/2}}$,
    $(e)\ \frac{n!}{n^n}$, $(f)\ \frac{n^3 + 5}{3^n + 2}$, $(g)\ \frac{1}{n^2 + n}$, $(\square)\frac{1}{\sqrt{n+1}}$,
    $(i)\cos n$, $(j)\frac{1}{n\log n}$, $(k)\frac{1}{n(\log n)^2}$.

Teaching Plan (Theory of BMATH204: Differential Equations):

Weeks 1 and 2: Differential equations and mathematical models, Order and degree of a differential equation, Exact differential equations and integrating factors of first order differential equations, Reducible second order differential equations.

[2] Chapter 1 (Sections 1.1 and 1.6).

[3] Chapter 2.

Week 3: Application of first order differential equations to acceleration-velocity model, Growth and decay model.

[2] Chapter 1 (Section 1.4, Pages 35 to 38), and Chapter 2 (Section 2.3).

[3] Chapter 3 (Section 3.3, A and B with Examples 3.8, 3.9).

Week 4: Introduction to compartmental models, Lake pollution model (with case study of Lake Burley Griffin).

[1] Chapter 2 (Sections 2.1, 2.5 and 2.6).

Week 5: Drug assimilation into the blood (case of a single cold pill, case of a course of cold pills, Case study of alcohol in the bloodstream).

[1] Chapter 2 (Sections 2.7 and 2.8).

Week 6: Exponential growth of population, Density dependent growth, Limited growth with harvesting.

[1] Chapter 3 (Sections 3.1 to 3.3).

Weeks 7 to 9: General solution of homogeneous equation of second order, Principle of superposition for a homogeneous equation; Wronskian, its properties and applications; Linear homogeneous and non-homogeneous equations of higher order with constant coefficients; Euler's equation.

[2] Chapter 3 (Sections 3.1 to 3.3).

Weeks 10 and 11: Method of undetermined coefficients, Method of variation of parameters; Applications of second order differential equations to mechanical vibrations.

[2] Chapter 3 (Sections 3.4 (Pages 172 to 177) and 3.5).

Weeks 12 to 14: Interacting population models, Epidemic model of influenza and its analysis, Predator-prey model and its analysis, Equilibrium points, Interpretation of the phase plane, Battle model and its analysis.

[1] Chapter 5 (Sections 5.1, 5.2, 5.4 and 5.9), and Chapter 6 (Sections 6.1 to 6.4).

Facilitating the Achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
1.	Learn basics of differential equations and mathematical modeling.	(i) Each topic to be explained with examples and illustrated on computers using Mathematica /MATLAB /Maple/Maxima/Scilab. (ii) Students to be involved in discussions and encouraged to ask questions. (iii) Students to be given homework/assignments. (iv) Students to be encouraged to give short presentations.	• Presentations and participation in discussions. • Assignments and class tests. • Mid-term examinations. • Practical and viva-voce examinations. • End-term examinations.
2.	Formulate differential equations for various mathematical models.		
3.	Solve first order non-linear differential equations and linear differential equations of higher order using various techniques.		
4.	Apply these techniques to solve and analyze various mathematical models.		

Keywords: Battle model, Epidemic model, Euler's equation, Exact differential equation, Integrating factor, Lake pollution model, Mechanical vibrations, Phase plane, Predator-prey model, Wronskian and its properties.

Semester-III

BMATH305: Theory of Real Functions

Total Marks: 100 (Theory: 75, Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: It is a basic course on the study of real valued functions that would develop an analytical ability to have a more matured perspective of the key concepts of calculus, namely, limits, continuity, differentiability and their applications.

Course Learning Outcomes: This course will enable the students to:

i) Have a rigorous understanding of the concept of limit of a function.
ii) Learn about continuity and uniform continuity of functions defined on intervals.
iii) Understand geometrical properties of continuous functions on closed and bounded intervals.
iv) Learn extensively about the concept of differentiability using limits, leading to a better understanding for applications.
v) Know about applications of mean value theorems and Taylor's theorem.

Unit 1: Limits of Functions
Limits of functions ($\varepsilon - \delta$ approach), Sequential criterion for limits, Divergence criteria, Limit theorems, One-sided limits, Infinite limits and limits at infinity.

Unit 2: Continuous Functions and their Properties
Continuous functions, Sequential criterion for continuity and discontinuity, Algebra of continuous functions, Properties of continuous functions on closed and bounded intervals; Uniform continuity, Non-uniform continuity criteria, Uniform continuity theorem.

Unit 3: Derivability and its Applications
Differentiability of a function, Algebra of differentiable functions, Carathéodory's theorem, Chain rule; Relative extrema, Interior extremum theorem, Rolle's theorem, Mean- value theorem and applications, Intermediate value property of derivatives, Darboux's theorem.

Unit 4: Taylor's Theorem and its Applications
Taylor polynomial, Taylor's theorem with Lagrange form of remainder, Application of Taylor's theorem in error estimation; Relative extrema, and to establish a criterion for convexity; Taylor's series expansions of e^x, $\sin x$ and $\cos x$.

Reference:

1. Bartle, Robert G., & Sherbert, Donald R. (2015). *Introduction to Real Analysis* (4th ed.). Wiley India Edition. New Delhi.

Additional Readings:

i. Ghorpade, Sudhir R. & Limaye, B. V. (2006). *A Course in Calculus and Real Analysis*. Undergraduate Texts in Mathematics, Springer (SIE). First Indian reprint.
ii. Mattuck, Arthur. (1999). *Introduction to Analysis*, Prentice Hall.

iii. Ross, Kenneth A. (2013). *Elementary Analysis*: *The Theory of Calculus* (2nd ed.). Undergraduate Texts in Mathematics, Springer. Indian Reprint.

Teaching Plan (BMATH305: Theory of Real Functions):

Week 1: Definition of the limit, Sequential criterion for limits, Criterion for non-existence of limit.
[1] Chapter 4 (Section 4.1).

Week 2: Algebra of limits of functions with illustrations and examples, Squeeze theorem.
[1] Chapter 4 (Section 4.2).

Week 3: Definition and illustration of the concepts of one-sided limits, Infinite limits and limits at infinity.
[1] Chapter 4 (Section 4.3).

Weeks 4 and 5: Definitions of continuity at a point and on a set, Sequential criterion for continuity, Algebra of continuous functions, Composition of continuous functions.
[1] Sections 5.1 and 5.2.

Weeks 6 and 7: Various properties of continuous functions defined on an interval, viz., Boundedness theorem, Maximum-minimum theorem, Statement of the location of roots theorem, Intermediate value theorem and the preservation of intervals theorem.
[1] Chapter 5 (Section 5.3).

Week 8: Definition of uniform continuity, Illustration of non-uniform continuity criteria, Uniform continuity theorem.
[1] Chapter 5 [Section 5.4 (5.4.1 to 5.4.3)].

Weeks 9 and 10: Differentiability of a function, Algebra of differentiable functions, Carathéodory's theorem and chain rule.
[1] Chapter 6 [Section 6.1 (6.1.1 to 6.1.7)].

Weeks 11 and 12: Relative extrema, Interior extremum theorem, Mean value theorem and its applications, Intermediate value property of derivatives - Darboux's theorem.
[1] Section 6.2.

Weeks 13 and 14: Taylor polynomial, Taylor's theorem and its applications, Taylor's series expansions of e^x, $\sin x$ and $\cos x$.
[1] Chapter 6 (Sections 6.4.1 to 6.4.6), and Chapter 9 (Example 9.4.14, Page 286).

Facilitating the Achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
1.	Have a rigorous understanding of the concept of limit of a function.	(i) Each topic to be explained with examples. (ii) Students to be involved in discussions and encouraged to ask questions. (iii) Students to be given homework/ assignments. (iv) Students to be encouraged to give short presentations. (v) Illustrate the concepts through CAS.	• Presentations and participation in discussions. • Assignments and class tests. • Mid-term examinations. • End-term examinations.
2.	Learn about continuity and uniform continuity of functions defined on intervals. Understand geometrical properties of continuous functions on closed and bounded intervals.		
3.	Learn extensively about the concept of differentiability using limits, leading to a better understanding for applications.		
4.	Know about applications of mean value theorems and Taylor's theorem.		

Keywords: Continuity, Convexity, Differentiability, Limit, Relative extrema, Rolle's theorem, Taylor's theorem, Uniform continuity.

BMATH306: Group Theory-I

Total Marks: 100 (Theory: 75, Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: The objective of the course is to introduce the fundamental theory of groups and their homomorphisms. Symmetric groups and group of symmetries are also studied in detail. Fermat's Little theorem as a consequence of the Lagrange's theorem on finite groups.

Course Learning Outcomes: The course will enable the students to:

i) Recognize the mathematical objects that are groups, and classify them as abelian, cyclic and permutation groups, etc.
ii) Link the fundamental concepts of groups and symmetrical figures.
iii) Analyze the subgroups of cyclic groups and classify subgroups of cyclic groups.
iv) Explain the significance of the notion of cosets, normal subgroups and factor groups.
v) Learn about Lagrange's theorem and Fermat's Little theorem.
vi) Know about group homomorphisms and group isomorphisms.

Unit 1: Groups and its Elementary Properties
Symmetries of a square, Dihedral groups, Definition and examples of groups including permutation groups and quaternion groups (illustration through matrices), Elementary properties of groups.

Unit 2: Subgroups and Cyclic Groups
Subgroups and examples of subgroups, Centralizer, Normalizer, Center of a group, Product of two subgroups; Properties of cyclic groups, Classification of subgroups of cyclic groups.

Unit 3: Permutation Groups and Lagrange's Theorem
Cycle notation for permutations, Properties of permutations, Even and odd permutations, Alternating groups; Properties of cosets, Lagrange's theorem and consequences including Fermat's Little theorem; Normal subgroups, Factor groups, Cauchy's theorem for finite abelian groups.

Unit 4: Group Homomorphisms
Group homomorphisms, Properties of homomorphisms, Group isomorphisms, Cayley's theorem, Properties of isomorphisms, First, Second and Third isomorphism theorems for groups.

Reference:

1. Gallian, Joseph. A. (2013). *Contemporary Abstract Algebra* (8th ed.). Cengage Learning India Private Limited, Delhi. Fourth impression, 2015.

Additional Reading:

i. Rotman, Joseph J. (1995). *An Introduction to The Theory of Groups* (4th ed.). Springer-Verlag, New York.

Teaching Plan (BMATH306: Group Theory-I):

Week 1: Symmetries of a square, Dihedral groups, Definition and examples of groups including permutation groups and quaternion groups (illustration through matrices).

[1] Chapter 1.

Week 2: Definition and examples of groups, Elementary properties of groups.

[1] Chapter 2.

Week 3: Subgroups and examples of subgroups, Centralizer, Normalizer, Center of a Group, Product of two subgroups.

[1] Chapter 3.

Weeks 4 and 5: Properties of cyclic groups. Classification of subgroups of cyclic groups.

[1] Chapter 4

Weeks 6 and 7: Cycle notation for permutations, Properties of permutations, Even and odd permutations, Alternating group.

[1] Chapter 5 (up to Page 110).

Weeks 8 and 9: Properties of cosets, Lagrange's theorem and consequences including Fermat's Little theorem.

[1] Chapter 7 (up to Example 6, Page 150).

Week 10: Normal subgroups, Factor groups, Cauchy's theorem for finite abelian groups.

[1] Chapters 9 (Theorem 9.1, 9.2, 9.3 and 9.5, and Examples 1 to 12).

Weeks 11 and 12: Group homomorphisms, Properties of homomorphisms, Group isomorphisms, Cayley's theorem.

[1] Chapter 10 (Theorems 10.1 and 10.2, Examples 1 to 11).

[1] Chapter 6 (Theorem 6.1, and Examples 1 to 8).

Weeks 13 and 14: Properties of isomorphisms, First, Second and Third isomorphism theorems.

[1] Chapter 6 (Theorems 6.2 and 6.3), Chapter 10 (Theorems 10.3, 10.4, Examples 12 to 14, and Exercises 41 and 42 for second and third isomorphism theorems for groups).

Facilitating the Achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
1.	Recognize the mathematical objects that are groups, and classify them as abelian, cyclic and permutation groups, etc. Link the fundamental concepts of groups and symmetrical figures.	(i) Each topic to be explained with examples. (ii) Students to be involved in discussions and encouraged to ask questions. (iii) Students to be given homework/assignments. (iv) Students to be encouraged to give short presentations.	• Presentations and participation in discussions. • Assignments and class tests. • Mid-term examinations. • End-term examinations.
2.	Analyze the subgroups of cyclic groups and classify subgroups of cyclic groups.		
3.	Explain the significance of the notion of cosets, normal subgroups and factor groups. Learn about Lagrange's theorem and Fermat's Little theorem.		
4.	Know about group homomorphisms and group isomorphisms.		

Keywords: Cauchy's theorem for finite Abelian groups, Cayley's theorem, Centralizer, Cyclic group, Dihedral group, Group homomorphism, Lagrange's theorem, Normalizer, Permutations.

BMATH307: Multivariate Calculus

Total Marks: 150 (Theory: 75, Internal Assessment: 25 and Practical: 50)
Workload: 4 Lectures, 4 Practicals (per week) **Credits:** 6 (4+2)
Duration: 14 Weeks (56 Hrs. Theory + 56 Hrs. Practical) **Examination:** 3 Hrs.

Course Objectives: To understand the extension of the studies of single variable differential and integral calculus to functions of two or more independent variables. Also, the emphasis will be on the use of Computer Algebra Systems by which these concepts may be analyzed and visualized to have a better understanding. This course will facilitate to become aware of applications of multivariable calculus tools in physics, economics, optimization, and understanding the architecture of curves and surfaces in plane and space etc.

Course Learning Outcomes: This course will enable the students to:

i) Learn the conceptual variations when advancing in calculus from one variable to multivariable discussion.
ii) Understand the maximization and minimization of multivariable functions subject to the given constraints on variables.
iii) Learn about inter-relationship amongst the line integral, double and triple integral formulations.
iv) Familiarize with Green's, Stokes' and Gauss divergence theorems.

Unit 1: Calculus of Functions of Several Variables
Functions of several variables, Level curves and surfaces, Limits and continuity, Partial differentiation, Higher order partial derivative, Tangent planes, Total differential and differentiability, Chain rule, Directional derivatives, The gradient, Maximal and normal property of the gradient, Tangent planes and normal lines.

Unit 2: Extrema of Functions of Two Variables and Properties of Vector Field
Extrema of functions of two variables, Method of Lagrange multipliers, Constrained optimization problems; Definition of vector field, Divergence and curl.

Unit 3: Double and Triple Integrals
Double integration over rectangular and nonrectangular regions, Double integrals in polar co-ordinates, Triple integral over a parallelopiped and solid regions, Volume by triple integrals, Triple integration in cylindrical and spherical coordinates, Change of variables in double and triple integrals.

Unit 4: Green's, Stokes' and Gauss Divergence Theorem
Line integrals, Applications of line integrals**:** Mass and Work, Fundamental theorem for line integrals, Conservative vector fields, Green's theorem, Area as a line integral, Surface integrals, Stokes' theorem, Gauss divergence theorem.

Reference:

1. Strauss, Monty J., Bradley, Gerald L., & Smith, Karl J. (2007). *Calculus* (3rd ed.). Dorling Kindersley (India) Pvt. Ltd. (Pearson Education). Delhi. Indian Reprint 2011.

Additional Reading:

i. Marsden, J. E., Tromba, A., & Weinstein, A. (2004). *Basic Multivariable Calculus*. Springer (SIE). First Indian Reprint.

Practical / Lab work to be performed in Computer Lab.

List of practicals to be done using Mathematica / MATLAB / Maple/Maxima/Scilab, etc.

1. Let $f(x)$ be any function and L be any real number. For given a and $\varepsilon > 0$ find a $\delta > 0$ such that for all x satisfying $0 < |x - a| < \delta$, the inequality $0 < |f(x) - l| < \varepsilon$ holds. For example:
   (i) $f(x) = x + 1,\ L = 5, a = 4, \varepsilon = 0.01$.
   (ii) $f(x) = \sqrt{x+1}, L = 1, a = 4, \varepsilon = 0.1$.
   (iii) $f(x) = x^2, L = 4, a = -2, \varepsilon = 0.5$.
   (iv) $f(x) = \frac{1}{x}, L = -1, a = -1, \varepsilon = 0.1$.
2. Discuss the limit of the following functions when x tends to 0:
   $$\pm\frac{1}{x}, \sin\left(\frac{1}{x}\right), \cos\left(\frac{1}{x}\right), x\sin\left(\frac{1}{x}\right), x\cos\left(\frac{1}{x}\right),\ x^2\sin\left(\frac{1}{x}\right),,$$
   $$\frac{1}{x^n}\ (n \in \mathbb{N}), [x] \text{ greatest integer function},\ \frac{1}{x}\sin\left(\frac{1}{x}\right).$$
3. Discuss the limit of the following functions when x tends to infinity:
   $$e^{\pm\frac{1}{x}}, \sin\left(\frac{1}{x}\right),\ \frac{1}{x}e^{\pm x},\ \frac{x}{x+1},\ x^2\sin\left(\frac{1}{x}\right),\ \frac{ax+b}{cx^2+dx+e}\ (a \neq 0, c \neq 0).$$
4. Discuss the continuity of the functions at $x = 0$ in the Practical 2.
5. Illustrate the geometric meaning of Rolle's theorem of the following functions on the given interval:
   (i) $x^3 - 4x$ on [–2, 2]; (ii) $(x-3)^4(x-5)^3$ on [3, 5] etc.
6. Illustrate the geometric meaning of Lagrange's mean value theorem of the following functions on the given interval:
   (i) $\log x$ on [1/2, 2]; (ii) $x(x-1)(x-2)$ on [0, 1/2]; (iii) $2x^2 - 7x + 10$ on [2, 5] etc.
7. Draw the following surfaces and find level curves at the given heights:
   (i) $f(x,y) = 10 - x^2 - y^2; z = 1, z = 6, z = 9$.
   (ii) $f(x,y) = x^2 + y^2; z = 1, z = 6, z = 9$.
   (iii) $f(x,y) = x^3 - y; z = 1, z = 6$.
   (iv) $f(x,y) = x^2 + \frac{y^2}{4}; z = 1, z = 5, z = 8$.
   (v) $f(x,y) = 4x^2 + y^2; z = 0, z = 6, z = 9$.
8. Draw the following surfaces and discuss whether limit exits or not as (x,y) approaches to the given points. Find the limit, if it exists:
   (i) $f(x,y) = \frac{x+y}{x-y}; (x,y) \to (0,0)$ and $(x,y) \to (1,3)$.
   (ii) $f(x,y) = \frac{x-y}{\sqrt{x^2+y^2}}; (x,y) \to (0,0)$ and $(x,y) \to (2,1)$.
   (iii) $f(x,y) = (x+y)e^{xy}; (x,y) \to (1,1)$ and $(x,y) \to (1,0)$.
   (iv) $f(x,y) = e^{xy}; (x,y) \to (0,0)$ and $(x,y) \to (1,0)$.
   (v) $f(x,y) = \frac{x+y^2}{x^2+y^2}; (x,y) \to (0,0)$.
   (vi) $f(x,y) = \frac{x^2-y^2}{x^2+y^2}; (x,y) \to (0,0)$ and $(x,y) \to (2,1)$.
9. Draw the tangent plane to the following surfaces at the given point:
   (i) $f(x,y) = \sqrt{x^2+y^2}$ at $(3,1,\sqrt{10})$.

(ii) $f(x,y) = 10 - x^2 - y^2$ at $(2,2,2)$.
(iii) $x^2 + y^2 + z^2 = 9$ at $(3,0,0)$.
(iii) $z = \tan^{-1}x$ at $\left(1, \sqrt{3}, \frac{\pi}{3}\right)$ and $(2,2,\frac{\pi}{4})$.
(iii) $z = \log|x + y^2|$ at $(-3,-2,0)$.

10. Use an incremental approximation to estimate the following functions at the given point and compare it with calculated value:
    (i) $f(x,y) = 3x^4 + 2y^4$ at $(1.01,2.03)$.
    (ii) $f(x,y) = x^5 - 2y^3$ at $(0.98,1.03)$.
    (iii) $f(x,y) = e^{xy}$ at $(1.01,0.98)$.
11. Find critical points and identify relative maxima, relative minima or saddle points to the following surfaces, if it exists:
    (i) $z = x^2 + y^2$; $(ii)\ z = 1 - x^2 - y^2$; $(iii)\ z = y^2 - x^2$; $(iv)\ z = x^2y^4$.
12. Draw the following regions D and check whether these regions are of Type I or Type II:
    (i) $D = \{(x,y): 0 \le x \le 2, 1 \le y \le e^x\}$.
    (ii) $D = \{(x,y): \log y \le x \le 2, 1 \le y \le e^2\}$.
    (iii) $D = \{(x,y): 0 \le x \le 1, x^3 \le y \le 1\}$.
    (iv) The region *D* bounded by $y = x^2 - 2$ and the line $y = x$.
    (v) $D = \left\{(x,y): 0 \le x \le \frac{\pi}{4}, \sin x \le y \le \cos x\right\}$.

Teaching Plan (Theory of BMATH307: Multivariate Calculus):

Week 1: Definition of functions of several variables, Graphs of functions of two variables – Level curves and surfaces, Limits and continuity of functions of two variables.
[1] Sections 11.1 and 11.2.

Week 2: Partial differentiation, and partial derivative as slope and rate, Higher order partial derivatives. Tangent planes, incremental approximation, Total differential.
[1] Chapter 11 (Sections 11.3 and 11.4).

Week 3: Differentiability, Chain rule for one parameter, Two and three independent parameters.
[1] Chapter 11 (Sections 11.4 and 11.5).

Week 4: Directional derivatives, The gradient, Maximal and normal property of the gradient, Tangent and normal lines.
[1] Chapter 11 (Section 11.6).

Week 5: First and second partial derivative tests for relative extrema of functions of two variables, and absolute extrema of continuous functions.
[1] Chapter 11 [Section 11.7 (up to page 605)].

Week 6: Lagrange multipliers method for optimization problems with one constraint, Definition of vector field, Divergence and curl.
[1] Sections 11.8 (Pages 610-614)] and 13.1.

Week 7: Double integration over rectangular and nonrectangular regions.
[1] Sections 12.1 and 12.2.

Week 8: Double integrals in polar co-ordinates, and triple integral over a parallelopiped.
[1] Chapter 12 (Sections 12.3 and 12.4).

Week 9: Triple integral over solid regions, Volume by triple integrals, and triple integration in cylindrical coordinates.
[1] Chapter 12 (Sections 12.4 and 12.5).

Week 10: Triple integration in spherical coordinates, Change of variables in double and triple integrals.
[1] Chapter 12 (Sections 12.5 and 12.6).

Week 11: Line integrals and its properties, applications of line integrals: mass and work.
[1] Chapter 13 (Section 13.2).

Week 12: Fundamental theorem for line integrals, Conservative vector fields and path independence.
[1] Chapter 13 (Section 13.3).
Week 13: Green's theorem for simply connected region, Area as a line integral, Definition of surface integrals.
[1] Chapter 13 [Sections 13.4 (Pages 712 to 716), 13.5 (Pages 723 to 726)].
Week 14: Stokes' theorem and the divergence theorem.
[1] Chapter 13 [Sections 13.6 (Pages 733 to 737), 13.7 (Pages 742 to 745)].

Note. To improve the problem solving ability, for similar kind of examples based upon the above contents, the Additional Reading (i) may be consulted.

Facilitating the Achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
1.	Learn the conceptual variations when advancing in calculus from one variable to multivariable discussion.	(i) Each topic to be explained with illustrations. (ii) Students to be encouraged to discover the relevant concepts. (iii) Students to be given homework/assignments. (iv) Discuss and solve the theoretical and practical problems in the class. (v) Students to be encouraged to apply concepts to real world problems.	• Presentations and class discussions. • Assignments and class tests. • Mid-term examinations. • Practical and viva-voce examinations. • End-term examinations.
2.	Understand the maximization and minimization of multivariable functions subject to the given constraints on variables.		
3.	Learn about inter-relationship amongst the line integral, double and triple integral formulations.		
4.	Familiarize with Green's, Stokes' and Gauss divergence theorems.		

Keywords: Directional derivatives, Double integral, Gauss divergence theorem, Green's theorem, Lagrange's multipliers, Level curves, Stokes' theorem, Volume integral, Vector field.

Skill Enhancement Paper

SEC-1: LaTeX and HTML

Total Marks: 100 (Theory: 38, Internal Assessment: 12, and Practical: 50)
Workload: 2 Lectures, 4 Practicals (per week) **Credits:** 4 (2+2)
Duration: 14 Weeks (28 Hrs. Theory + 56 Hrs. Practical) **Examination:** 2 Hrs.

Course Objectives: The purpose of this course is to acquaint students with the latest typesetting skills, which shall enable them to prepare high quality typesetting, beamer presentation and webpages.

Course Learning Outcomes: After studying this course the student will be able to:

i) Create and typeset a LaTeX document.
ii) Typeset a mathematical document using LaTex.
iii) Learn about pictures and graphics in LaTex.
iv) Create beamer presentations.
v) Create web page using HTML.

Unit 1: Getting Started with LaTeX
Introduction to TeX and LaTeX, Typesetting a simple document, Adding basic information to a document, Environments, Footnotes, Sectioning and displayed material.

Unit 2: Mathematical Typesetting with LaTeX
Accents and symbols, Mathematical typesetting (elementary and advanced)**:** Subscript/ Superscript, Fractions, Roots, Ellipsis, Mathematical Symbols, Arrays, Delimiters, Multiline formulas, Spacing and changing style in math mode.

Unit 3: Graphics and Beamer Presentation in LaTeX
Graphics in LaTeX, Simple pictures using PSTricks, Plotting of functions, Beamer presentation.

Unit 4: HTML
HTML basics, Creating simple web pages, Images and links, Design of web pages.

References:

1. Bindner, Donald & Erickson, Martin. (2011). *A Student's Guide to the Study, Practice, and Tools of Modern Mathematics*. CRC Press, Taylor & Francis Group, LLC.
2. Lamport, Leslie (1994). *LaTeX*: *A Document Preparation System*, User's Guide and Reference Manual (2nd ed.). Pearson Education. Indian Reprint.

Additional Readings:

i. Dongen, M. R. C. van (2012). *LaTeX and Friends*. Springer-Verlag.
ii. Robbins, J. N. (2018). *Learning Web Design*: *A Beginner's Guide to HTML* (5th ed.). O'Reilly Media Inc.

Practical / Lab work to be performed in Computer Lab.

[1] Chapter 9 (Exercises 4 to 10), Chapter 10 (Exercises 1 to 4 and 6 to 9),
Chapter 11 (Exercises 1, 3, 4, and 5), and Chapter 15 (Exercises 5, 6 and 8 to 11).

Teaching Plan (Theory of SEC-1: LaTeX and HTML):

Weeks 1 to 3: Introduction to TeX and LaTeX, Typesetting a simple document, Adding basic information to a document, Environments, Footnotes, Sectioning and displayed material.

[1] Chapter 9 (9.1 to 9.5).
[2] Chapter 2 (2.1 to 2.5).

Weeks 4 to 6: Accents of symbols, Mathematical typesetting (elementary and advanced): Subscript/Superscript, Fractions, Roots, Ellipsis, Mathematical symbols, Arrays, Delimiters, Multiline formulas, Spacing and changing style in math mode.

[1] Chapter 9 (9.6 and 9.7).
[2] Chapter 3 (3.1 to 3.3).

Weeks 7 and 8: Graphics in LaTeX, Simple pictures using PSTricks, Plotting of functions.

[1] Chapter 9 (Section 9.8). Chapter 10 (10.1 to 10.3).
[2] Chapter 7 (7.1 and 7.2).

Weeks 9 and 10: Beamer presentation.

[1] Chapter 11 (Sections 11.1 to 11.4).

Weeks 11 and 12: HTML basics, Creating simple web pages.

[1] Chapter 15 (Sections 15.1 and 15.2).

Weeks 13 and 14: Adding images and links, Design of web pages.

[1] Chapter 15 (Sections 15.3 to 15.5).

Facilitating the Achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
1.	Create and typeset a LaTeX document.	(i) Each topic to be explained with illustrations on computers. (ii) Students be given homework/ assignments. (iii) Students be encouraged to create simple webpages.	• Presentations and class discussions. • Assignments and class tests. • Mid-term examinations. • End-term examinations.
2.	Typeset a mathematical document using LaTex.		
3.	Learn about pictures and graphics in LaTex. Create beamer presentations.		
4.	Create web page using HTML.		

Keywords: LaTex, Mathematical typesetting, PSTricks, Beamer, HTML.

Semester-IV

BMATH408: Partial Differential Equations

Total Marks: 150 (Theory: 75, Internal Assessment: 25 and Practical: 50)
Workload: 4 Lectures, 4 Practicals (per week) **Credits:** 6 (4+2)
Duration: 14 Weeks (56 Hrs. Theory + 56 Hrs. Practical) **Examination:** 3 Hrs.

Course Objectives: The main objectives of this course are to teach students to form and solve partial differential equations and use them in solving some physical problems.

Course Learning Outcomes: The course will enable the students to:

i) Formulate, classify and transform first order PDEs into canonical form.
ii) Learn about method of characteristics and separation of variables to solve first order PDE's.
iii) Classify and solve second order linear PDEs.
iv) Learn about Cauchy problem for second order PDE and homogeneous and non-homogeneous wave equations.
v) Apply the method of separation of variables for solving many well-known second order PDEs.

Unit 1: First Order PDE and Method of Characteristics
Introduction, Classification, Construction and geometrical interpretation of first order partial differential equations (PDE), Method of characteristic and general solution of first order PDE, Canonical form of first order PDE, Method of separation of variables for first order PDE.

Unit 2: Mathematical Models and Classification of Second Order Linear PDE
Gravitational potential, Conservation laws and Burger's equations, Classification of second order PDE, Reduction to canonical forms, Equations with constant coefficients, General solution.

Unit 3: The Cauchy Problem and Wave Equations
Mathematical modeling of vibrating string and vibrating membrane, Cauchy problem for second order PDE, Homogeneous wave equation, Initial boundary value problems, Non-homogeneous boundary conditions, Finite strings with fixed ends, Non-homogeneous wave equation, Goursat problem.

Unit 4: Method of Separation of Variables
Method of separation of variables for second order PDE, Vibrating string problem, Existence and uniqueness of solution of vibrating string problem, Heat conduction problem, Existence and uniqueness of solution of heat conduction problem, Non-homogeneous problem.

Reference:

1. Myint-U, Tyn & Debnath, Lokenath. (2007). *Linear Partial Differential Equation for Scientists and Engineers* (4th ed.). Springer, Third Indian Reprint, 2013.

Additional Readings:

i. Sneddon, I. N. (2006). *Elements of Partial Differential Equations*, Dover Publications. Indian Reprint.

ii. Stavroulakis, Ioannis P & Tersian, Stepan A. (2004). *Partial Differential Equations: An Introduction with Mathematica and* MAPLE (2nd ed.). World Scientific.

Practical / Lab work to be performed in a Computer Lab:

Modeling of the following similar problems using Mathematica/MATLAB/Maple/Maxima/Scilab etc.

1. Solution of Cauchy problem for first order PDE.
2. Plotting the characteristics for the first order PDE.
3. Plot the integral surfaces of a given first order PDE with initial data.
4. Solution of wave equation $\frac{\partial^2 u}{\partial t^2} = c^2 \frac{\partial^2 u}{\partial x^2}$ for any two of the following associated conditions:
   (i) $u(x,0) = \phi(x), \quad u(x,0) = \psi(x), \ x \in \mathbb{R}, \ t > 0.$
   (ii) $u(x,0) = \phi(x), \ u_t(x,0) = \psi(x), \quad u(0,t) = 0, x > 0 \ t > 0.$
   (iii) $u(x,0) = \phi(x), \ u_t(x,0) = \psi(x), \ u_x(0,t) = 0, \ x > 0, \ t > 0.$
   (iv) $u(x,0) = \phi(x), \quad u(x,0) = \psi(x), \quad u(0,t) = 0, \ u(l,t) = 0, 0 < x < l, \ t > 0.$
5. Solution of one-dimensional heat equation $u_t = k\, u_{xx}$, for a homogeneous rod of length l. That is - solve the IBVP:
$$u_t = k\, u_{xx}, \qquad 0 < x < l, \qquad t > 0,$$
$$u(0,t) = 0, \qquad u(l,t) = 0, \qquad t \geq 0,$$
$$u(0,t) = f(x), \ \ 0 \leq x \leq l.$$
6. Solving systems of ordinary differential equations.
7. Draw the following sequence of functions on the given interval and discuss the pointwise convergence:
   (i) $f_n(x) = x^n$ for $x \in \mathbb{R}$,
   (ii) $f_n(x) = \frac{x}{n}$ for $x \in \mathbb{R}$,
   (iii) $f_n(x) = \frac{x^2+nx}{n}$ for $x \in \mathbb{R}$,
   (iv) $f_n(x) = \frac{\sin nx + n}{n}$ for $x \in \mathbb{R}$
   (v) $f_n(x) = \frac{x}{x+n}$ for $x \in \mathbb{R}\ x \geq 0$,
   (vi) $f_n(x) = \frac{nx}{1+n^2x^2}$ for $x \in \mathbb{R}$
   (vii) $f_n(x) = \frac{nx}{1+nx}$ for $x \in \mathbb{R}, x \geq 0$,
   (viii) $f_n(x) = \frac{x^n}{1+x^n}$ for $x \in \mathbb{R}, x \geq 0$
8. Discuss the uniform convergence of sequence of functions (i) to (viii) given above in (7).

Teaching Plan (Theory of BMATH408: Partial Differential Equations):

Week 1: Introduction, Classification, Construction of first order partial differential equations (PDE).
[1] Chapter 2 (Sections 2.1 to 2.3).

Week 2: Method of characteristics and general solution of first order PDE.
[1] Chapter 2 (Sections 2.4 and 2.5).

Week 3: Canonical form of first order PDE, Method of separation of variables for first order PDE.
[1] Chapter 2 (Sections 2.6 and 2.7).

Week 4: The vibrating string, Vibrating membrane, Gravitational potential, Conservation laws.
[1] Chapter 3 (Sections 3.1 to 3.3, 3.5 and 3.6).

Weeks 5 and 6: Reduction to canonical forms, Equations with constant coefficients, General solution.
[1] Chapter 4 (Sections 4.1 to 4.5).

Weeks 7 and 8: The Cauchy problem for second order PDE, Homogeneous wave equation.
[1] Chapter 5 (Sections 5.1, 5.3 and 5.4).

Weeks 9 and 10: Initial boundary value problem, Non-homogeneous boundary conditions, Finite string with fixed ends, Non-homogeneous wave equation, Goursat problem.

[1] Chapter 5 (Sections 5.5 to 5. and 5.9).

Weeks 11 and 12: Method of separation of variables for second order PDE, Vibrating string problem.

[1] Chapter 7 (Sections 7.1 to 7.3).

Weeks 13 and 14: Existence (omit proof) and uniqueness of vibrating string problem. Heat conduction problem. Existence (omit proof) and uniqueness of the solution of heat conduction problem. Non-homogeneous problem.

[1] Chapter 7 (Sections 7.4 to 7.6 and 7.8).

Facilitating the Achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
1.	Formulate, classify and transform first order PDEs into canonical form. Learn about method of characteristics and separation of variables to solve first order PDEs.	(i) Each topic to be explained with examples. (ii) Students to be encouraged to discover the relevant concepts. (iii) Students to be given homework/ assignments. (iv) Discuss and solve the theoretical and practical problems in the class. (v) Students to be encouraged to apply concepts to real world problems.	• Presentations and class discussions. • Assignments and class tests. • Mid-term examinations. • Practical and viva-voce examinations. • End-term examinations.
2.	Classify and solve second order linear PDEs.		
3.	Learn about Cauchy problem for second order PDE and homogeneous and non-homogeneous wave equations.		
4.	Apply the method of separation of variables for solving many well-known second order PDEs.		

Keywords: Cauchy problem, Characteristics, Conservation laws and Burger's equations, Heat equation, Vibrating membrane, Wave equation.

BMATH409: Riemann Integration & Series of Functions

Total Marks: 100 (Theory: 75 and Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: To understand the integration of bounded functions on a closed and bounded interval and its extension to the cases where either the interval of integration is infinite, or the integrand has infinite limits at a finite number of points on the interval of integration. The sequence and series of real valued functions, and an important class of series of functions (i.e., power series).

Course Learning Outcomes: The course will enable the students to:

i) Learn about some of the classes and properties of Riemann integrable functions, and the applications of the Fundamental theorems of integration.
ii) Know about improper integrals including, beta and gamma functions.
iii) Learn about Cauchy criterion for uniform convergence and Weierstrass M-test for uniform convergence.
iv) Know about the constraints for the inter-changeability of differentiability and integrability with infinite sum.
v) Approximate transcendental functions in terms of power series as well as, differentiation and integration of power series.

Unit 1: Riemann Integration
Definition of Riemann integration, Inequalities for upper and lower Darboux sums, Necessary and sufficient conditions for the Riemann integrability, Definition of Riemann integration by Riemann sum and equivalence of the two definitions, Riemann integrability of monotone functions and continuous functions, Properties of Riemann integrable functions, Definitions of piecewise continuous and piecewise monotone functions and their Riemann integrability, intermediate value theorem for integrals, Fundamental theorems (I and II) of calculus, and the integration by parts.

Unit 2: Improper Integral
Improper integrals of Type-I, Type-II and mixed type, Convergence of beta and gamma functions, and their properties.

Unit 3: Sequence and Series of Functions
Pointwise and uniform convergence of sequence of functions, Theorem on the continuity of the limit function of a sequence of functions, Theorems on the interchange of the limit and derivative, and the interchange of the limit and integrability of a sequence of functions. Pointwise and uniform convergence of series of functions, Theorems on the continuity, derivability and integrability of the sum function of a series of functions, Cauchy criterion and the Weierstrass M-test for uniform convergence.

Unit 4: Power Series
Definition of a power series, Radius of convergence, Absolute convergence (Cauchy–Hadamard theorem), Uniform convergence, Differentiation and integration of power series, Abel's theorem.

References:

1. Bartle, Robert G., & Sherbert, Donald R. (2015). *Introduction to Real Analysis* (4th ed.). Wiley India Edition. Delhi.
2. Denlinger, Charles G. (2011). *Elements of Real Analysis*. Jones & Bartlett (Student Edition). First Indian Edition. Reprinted 2015.
3. Ghorpade, Sudhir R. & Limaye, B. V. (2006). *A Course in Calculus and Real Analysis*. Undergraduate Texts in Mathematics, Springer (SIE). First Indian reprint.
4. Ross, Kenneth A. (2013). *Elementary Analysis*: *The Theory of Calculus* (2nd ed.). Undergraduate Texts in Mathematics, Springer.

Additional Reading:

i. Bilodeau, Gerald G., Thie, Paul R., & Keough, G. E. (2010). *An Introduction to Analysis* (2nd ed.). Jones & Bartlett India Pvt. Ltd. Student Edition. Reprinted 2015.

Teaching Plan (BMATH409: Riemann Integration & Series of Functions):

Week 1: Definition of Riemann integration, Inequalities for upper and lower Darboux sums.
[4] Chapter 6 [Section 32 (32.1 to 32.4)].

Week 2: Necessary and sufficient conditions for the Riemann integrability, Definition of Riemann integration by Riemann sum and equivalence of the two definitions.
[4] Chapter 6 [Section 32 (32.5 to 32.10)].

Week 3: Riemann integrability of monotone functions and continuous functions, Algebra and properties of Riemann integrable functions.
[4] Chapter 6 [Section 33 (33.1 to 33.6)].

Week 4: Definitions of piecewise continuous and piecewise monotone functions and their Riemann integrability, Intermediate value theorem for integrals.
[4] Chapter 6 [Section 33 (33.7 to 33.10)].

Week 5: First and second fundamental theorems of integral calculus, and the integration by parts.
[4] Chapter 6 [Section 34 (34.1 to 34.3)].

Week 6: Improper integrals of Type-I, Type-II and mixed type.
[2] Chapter 7 [Section 7.8 (7.8.1 to 7.8.18)].

Week 7: Convergence of beta and gamma functions, and their properties.
[3] Pages 405-408.

Week 8: Definitions and examples of pointwise and uniformly convergent sequence of functions.
[1] Chapter 8 [Section 8.1 (8.1.1 to 8.1.10)].

Week 9: Motivation for uniform convergence by giving examples, Theorem on the continuity of the limit function of a sequence of functions.
[1] Chapter 8 [Section 8.2 (8.2.1 to 8.2.2)].

Week 10: The statement of the theorem on the interchange of the limit function and derivative, and its illustration with the help of examples, The interchange of the limit function and integrability of a sequence of functions.
[1] Chapter 8 [Section 8.2 (Theorems 8.2.3 and 8.2.4)].

Week 11: Pointwise and uniform convergence of series of functions, Theorems on the continuity, derivability and integrability of the sum function of a series of functions.
[1] Chapter 9 [Section 9.4 (9.4.1 to 9.4.4)].

Week 12: Cauchy criterion for the uniform convergence of series of functions, and the Weierstrass M-test for uniform convergence.
[2] Chapter 9 [Section 9.4 (9.4.5 to 9.4.6)].

Week 13: Definition of a power series, Radius of convergence, Absolute and uniform convergence of a power series.
[4] Chapter 4 (Section 23).

Week 14: Differentiation and integration of power series, Statement of Abel's theorem and its illustration with the help of examples.
[4] Chapter 4 [Section 26 (26.1 to 26.6)].

Facilitating the Achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
1.	Learn about some of the classes and properties of Riemann integrable functions, and the applications of the fundamental theorems of integration.	(i) Each topic to be explained with examples. (ii) Students to be involved in discussions and encouraged to ask questions. (iii) Students to be given homework/assignments. (iv) Students to be encouraged to give short presentations.	• Presentations and participation in discussions. • Assignments and class tests. • Mid-term examinations. • End-term examinations.
2.	Know about improper integrals including, beta and gamma functions.		
3.	Learn about Cauchy criterion for uniform convergence and Weierstrass M-test for uniform convergence. Know about the constraints for the inter-changeability of differentiability and integrability with infinite sum.		
4.	Approximate transcendental functions in terms of power series as well as, differentiation and integration of power series.		

Keywords: Beta function, Gamma function, Improper integral, Power series, Radius of convergence, Riemann integration, Uniform convergence, Weierstrass M-test.

BMATH410: Ring Theory & Linear Algebra-I

Total Marks: 100 (Theory: 75 and Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: The objective of this course is to introduce the fundamental theory of two objects, namely - rings and vector spaces, and their corresponding homomorphisms.

Course Learning Outcomes: The course will enable the students to:

i) Learn about the fundamental concept of rings, integral domains and fields.
ii) Know about ring homomorphisms and isomorphisms theorems of rings.
iii) Learn about the concept of linear independence of vectors over a field, and the dimension of a vector space.
iv) Basic concepts of linear transformations, dimension theorem, matrix representation of a linear transformation, and the change of coordinate matrix.

Unit 1: Introduction of Rings
Definition and examples of rings, Properties of rings, Subrings, Integral domains and fields, Characteristic of a ring, Ideals, Ideal generated by a subset of a ring, Factor rings, Operations on ideals, Prime and maximal ideals.

Unit 2: Ring Homomorphisms
Ring homomorphisms, Properties of ring homomorphisms, First, Second and Third Isomorphism theorems for rings, The Field of quotients.

Unit 3: Introduction of Vector Spaces
Vector spaces, Subspaces, Algebra of subspaces, Quotient spaces, Linear combination of vectors, Linear span, Linear independence, Basis and dimension, Dimension of subspaces.

Unit 4: Linear Transformations
Linear transformations, Null space, Range, Rank and nullity of a linear transformation, Matrix representation of a linear transformation, Algebra of linear transformations, Isomorphisms, Isomorphism theorems, Invertibility and the change of coordinate matrix.

References:

1. Gallian, Joseph. A. (2013). *Contemporary Abstract Algebra* (8th ed.). Cengage Learning India Private Limited. Delhi. Fourth impression, 2015.
2. Friedberg, Stephen H., Insel, Arnold J., & Spence, Lawrence E. (2003). *Linear Algebra* (4th ed.). Prentice-Hall of India Pvt. Ltd. New Delhi.

Additional Readings:

i. Dummit, David S., & Foote, Richard M. (2016). *Abstract Algebra* (3rd ed.). Student Edition. Wiley India.
ii. Herstein, I. N. (2006). *Topics in Algebra* (2nd ed.). Wiley Student Edition. India.
iii. Hoffman, Kenneth, & Kunze, Ray Alden (1978). *Linear Algebra* (2nd ed.). Prentice-Hall of India Pvt. Limited. Delhi. Pearson Education India Reprint, 2015.

Teaching Plan (BMATH410: Ring Theory & Linear Algebra-I):

Week 1: Definition and examples of rings, Properties of rings, Subrings.
[1] Chapter 12.

Week 2: Integral domains and fields, Characteristic of a ring.
[1] Chapter 13.

Week 3 and 4: Ideals, Ideal generated by a subset of a ring, Factor rings, Operations on ideals, Prime and maximal ideals.
[1] Chapter 14.

Week 5: Ring homomorphisms, Properties of ring homomorphisms.
[1] Chapter 15 (up to Theorem 15.2).

Week 6: First, Second and Third Isomorphism theorems for rings, The field of quotients.
[1] Chapter 15 (Theorems 15.3 to 15.6, Examples 10 to 12), and Exercises 3 and 4 on Page 347.

Week 7: Vector spaces, Subspaces, Algebra of subspaces.
[2] Chapter 1 (Sections 1.2 and 1.3).

Week 8: Linear combination of vectors, Linear span, Linear independence.
[2] Chapter 1 (Sections 1.4 and 1.5).

Weeks 9 and 10: Bases and dimension. Dimension of subspaces.
[2] Chapter 1 (Section 1.6).

Week 11: Linear transformations, Null space, Range, Rank and nullity of a linear transformation.
[2] Chapter 2 (Section 2.1).

Weeks 12 and 13: Matrix representation of a linear transformation, Algebra of linear transformations.
[2] Chapter 2 (Sections 2.2 and 2.3).

Week 14: Isomorphisms, Isomorphism theorems, Invertibility and the change of coordinate matrix.
[2] Chapter 2 (Sections 2.4 and 2.5).

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
1.	Learn about the fundamental concept of rings, integral domains and fields.	(i) Each topic to be explained with examples. (ii) Students to be involved in discussions and encouraged to ask questions. (iii) Students to be given homework/assignments. (iv) Students to be encouraged to give short presentations.	• Presentations and participation in discussions. • Assignments and class tests. • Mid-term examinations. • End-term examinations.
2.	Know about ring homomorphisms and isomorphisms theorems of rings.		
3.	Learn about the concept of linear independence of vectors over a field, and the dimension of a vector space.		
4.	Basic concepts of linear transformations, dimension theorem, matrix representation of a linear transformation, and the change of coordinate matrix.		

Keywords: Basis and dimension of a vector space, Characteristic of a ring, Integral domain, Isomorphism theorems for rings, Linear transformations, Prime and maximal ideals, Quotient field, Vector space.

Skill Enhancement Paper

SEC-2: Computer Algebra Systems and Related Software

Total Marks: 100 (Theory: 38, Internal Assessment: 12, and Practical: 50)
Workload: 2 Lectures, 4 Practicals (per week) **Credits:** 4 (2+2)
Duration: 14 Weeks (28 Hrs. Theory + 56 Hrs. Practical) **Examination**: 2 Hrs.

Course Objectives: This course aims at familiarizing students with the usage of computer algebra systems (/Mathematica/MATLAB/Maxima/Maple) and the statistical software **R**. The basic emphasis is on plotting and working with matrices using CAS. Data entry and summary commands will be studied in **R**. Graphical representation of data shall also be explored.

Course Learning Outcomes: This course will enable the students to:

i) Use of computer algebra systems (Mathematica/MATLAB/Maxima/Maple etc.) as a calculator, for plotting functions and animations
ii) Use of CAS for various applications of matrices such as solving system of equations and finding eigenvalues and eigenvectors.
iii) Understand the use of the statistical software **R** as calculator and learn to read and get data into **R.**
iv) Learn the use of **R** in summary calculation, pictorial representation of data and exploring relationship between data.
v) Analyze, test, and interpret technical arguments on the basis of geometry.

Unit 1: Introduction to CAS and Applications
Computer Algebra System (CAS), Use of a CAS as a calculator, Computing and plotting functions in 2D, Plotting functions of two variables using Plot3D and ContourPlot, Plotting parametric curves surfaces, Customizing plots, Animating plots, Producing tables of values, working with piecewise defined functions, Combining graphics.

Unit 2: Working with Matrices
Simple programming in a CAS, Working with matrices, Performing Gauss elimination, operations (transpose, determinant, inverse), Minors and cofactors, Working with large matrices, Solving system of linear equations, Rank and nullity of a matrix, Eigenvalue, eigenvector and diagonalization.

Unit 3: R - The Statistical Programming Language
R as a calculator, Explore data and relationships in **R.** Reading and getting data into **R:** Combine and scan commands, Types and structure of data items with their properties, Manipulating vectors, Data frames, Matrices and lists, Viewing objects within objects, Constructing data objects and conversions.

Unit 4: Data Analysis with R
Summary commands**:** Summary statistics for vectors, Data frames, Matrices and lists, Summary tables, Stem and leaf plot, Histograms, Plotting in **R:** Box-whisker plots, Scatter plots, Pairs plots, Line charts, Pie charts, Cleveland dot charts and bar charts, Copy and save graphics to other applications.

References:

1. Bindner, Donald & Erickson, Martin. (2011). *A Student's Guide to the Study, Practice, and Tools of Modern Mathematics*. CRC Press, Taylor & Francis Group, LLC.
2. Torrence, Bruce F., & Torrence, Eve A. (2009). *The Student's Introduction to Mathematica®: A Handbook for Precalculus, Calculus, and Linear Algebra* (2nd ed.). Cambridge University Press.
3. Gardener, M. (2012). *Beginning R: The Statistical Programming Language*, Wiley.

Additional Reading:

i. Verzani, John (2014). *Using R for Introductory Statistics* (2nd ed.). CRC Press, Taylor & Francis Group.

Note: Theoretical and Practical demonstration should be carried out only in **one** of the CAS: Mathematica/MATLAB/Maxima/Scilab or any other.

Practical / Lab work to be performed in Computer Lab.

[1] Chapter 12 (Exercises 1 to 4 and 8 to 12), Chapter 14 (Exercises 1 to 3)
[2] Chapter 3 [Exercises 3.2(1 and 2), 3.3(1, 2 and 4), 3.4(1 and 2), 3.5(1 to 4), 3.6(2 and 3)].
[2] Chapter 6 (Exercises 6.2 and 6.3) and Chapter 7 [Exercises 7.1(1), 7.2, 7.3(2), 7.4(1) and 7.6].

Note: Relevant exercises of [3] Chapters 2 to 5 and 7 (The practical may be done on the database to be downloaded from http://data.gov.in/).

Teaching Plan (Theory of SEC-1: Computer Algebra Systems and Related Software):

Weeks 1 to 3: Computer Algebra System (CAS), Use of a CAS as a calculator, Computing and plotting functions in 2D, Producing tables of values, Working with piecewise defined functions, Combining graphics. Simple programming in a CAS.
[1] Chapter 12 (Sections 12.1 to 12.5).
[2] Chapter 1, and Chapter 3 (Sections 3.1 to 3.6 and 3.8).

Weeks 4 and 5: Plotting functions of two variables using Plot3D and contour plot, Plotting parametric curves surfaces, Customizing plots, Animating plots.
[2] Chapter 6 (Sections 6.2 and 6.3).

Weeks 6 to 8: Working with matrices, Performing Gauss elimination, Operations (Transpose, Determinant, Inverse), Minors and cofactors, Working with large matrices, Solving system of linear equations, Rank and nullity of a matrix, Eigenvalue, Eigenvector and diagonalization.
[2] Chapter 7 (Sections 7.1 to 7.8).

Weeks 9 to 11: R as a calculator, Explore data and relationships in **R.** Reading and getting data into **R:** Combine and scan commands, Types and structure of data items with their properties. Manipulating vectors, Data frames, Matrices and lists. Viewing objects within objects. Constructing data objects and conversions.
[1] Chapter 14 (Sections 14.1 to 14.4).
[3] Chapter 2, and Chapter 3.

Weeks 12 to 14: Summary commands**:** Summary statistics for vectors, Data frames, Matrices and lists. Summary tables. Stem and leaf plot, histograms. Plotting in **R:** Box-whisker plots, Scatter plots, Pairs plots, Line charts, Pie charts, Cleveland dot charts and Bar charts. Copy and save graphics to other applications.

[1] Chapter 14 (Section 14.7).
[3] Chapter 5 (up to Page 157), and Chapter 7.

Facilitating the Achievement of Course Learning Outcomes

<table>
<tr><th>Unit No.</th><th>Course Learning Outcomes</th><th>Teaching and Learning Activity</th><th>Assessment Tasks</th></tr>
<tr><td>1.</td><td>Use of computer algebra systems (Mathematica/MATLAB/Maxima/Maple etc.) as a calculator, for plotting functions and animations</td><td rowspan="4">(i) Each topic to be explained with illustrations using CAS or R.
(ii) Students to be given homework/ assignments.
(iii) Students to be encouraged to do look for new applications.</td><td rowspan="4">• Presentations and class discussions.
• Assignments and class tests.
• Mid-term examinations.
• End-term examinations.</td></tr>
<tr><td>2.</td><td>Use of CAS for various applications of matrices such as solving system of equations and finding eigenvalues and eigenvectors.</td></tr>
<tr><td>3.</td><td>Understand the use of the statistical software R as calculator and learn to read and get data into R.</td></tr>
<tr><td>4.</td><td>Learn the use of R in summary calculation, pictorial representation of data and exploring relationship between data.
Analyze, test, and interpret technical arguments on the basis of geometry.</td></tr>
</table>

Keywords: Plot3D, ContourPlot, Calculator, Summary commands, Histograms.

Semester-V

BMATH511: Metric Spaces

Total Marks: 100 (Theory: 75, Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: Up to this stage, students do study the concepts of analysis which evidently rely on the notion of distance. In this course, the objective is to develop the usual idea of distance into an abstract form on any set of objects, maintaining its inherent characteristics, and the resulting consequences.

Course Learning Outcomes: The course will enable the students to:

i) Learn various natural and abstract formulations of distance on the sets of usual or unusual entities. Become aware one such formulations leading to metric spaces.
ii) Analyse how a theory advances from a particular frame to a general frame.
iii) Appreciate the mathematical understanding of various geometrical concepts, viz. balls or connected sets etc. in an abstract setting.
iv) Know about Banach fixed point theorem, whose far-reaching consequences have resulted into an independent branch of study in analysis, known as fixed point theory.
v) Learn about the two important topological properties, namely connectedness and compactness of metric spaces.

Unit 1: Basic Concepts
Metric spaces: Definition and examples, Sequences in metric spaces, Cauchy sequences, Complete metric space.

Unit 2: Topology of Metric Spaces

Open and closed ball, Neighborhood, Open set, Interior of a set, Limit point of a set, Derived set, Closed set, Closure of a set, Diameter of a set, Cantor's theorem, Subspaces, Dense set.

Unit 3: Continuity & Uniform Continuity in Metric Spaces

Continuous mappings, Sequential criterion and other characterizations of continuity, Uniform continuity, Homeomorphism, Contraction mapping, Banach fixed point theorem.

Unit 4: Connectedness and Compactness
Connectedness, Connected subsets of $\mathbb{R}$, Connectedness and continuous mappings, Compactness, Compactness and boundedness, Continuous functions on compact spaces.

Reference:

1. Shirali, Satish & Vasudeva, H. L. (2009). *Metric Spaces*, Springer, First Indian Print.

Additional Readings:

i. Kumaresan, S. (2014). *Topology of Metric Spaces* (2nd ed.). Narosa Publishing House. New Delhi.
ii. Simmons, George F. (2004). *Introduction to Topology and Modern Analysis*. McGraw-Hill Education. New Delhi.

Teaching Plan (BMATH511: Metric Spaces):

Week 1: Definition of metric space, Illustration using the usual metric on ℝ, Euclidean and max metric on $\mathbb{R}^2$, Euclidean and max metric on $\mathbb{R}^n$, Discrete metric, Sup metric on B(S) and C[a, b], Integral metric on C[a, b].

[1] Chapter 1 [Section 1.2 (1.2.1, 1.2.2 ((i), (ii), (iv), (v), (viii), (ix), (x)), 1.2.3 and 1.2.4 (i))]

Week 2: Sequences in metric space, Definition of limit of a sequence, Illustration through examples, Cauchy sequences.

[1] Chapter 1 [Section 1.3 (1.3.1, 1.3.2, 1.3.3 ((i), (iv)), 1.3.5) and Section 1.4 (1.4.1 to 1.4.4)]

Week 3: Definition of complete metric spaces, Illustration through examples.

[1] Chapter 1 [Section 1.4 (1.4.5 to 1.4.7, 1.4.12 to 1.4.14(ii))].

Week 4: Open and closed balls, Neighborhood, Open sets, Examples and basic results.

[1] Chapter 2 [Section 2.1 (2.1.1 to 2.1.11 (except 2.1.6(ii)))].

Week 5: Interior point, Interior of a set, Limit point, Derived set, Examples and basic results.

[1] Chapter 2 [Section 2.1 (2.1.12 to 2.1.20)].

Week 6: Closed set, Closure of a set, Examples and basic results.

[1] Chapter 2 [Section 2.1 (2.1.21 to 2.1.35)].

Week 7: Bounded set, Diameter of a set, Cantor's theorem.

[1] Chapter 2 [Section 2.1 (2.1.41 to 2.1.44)].

Week 8: Relativisation and subspaces, Dense sets.

[1] Chapter 2 [Section 2.2 (2.2.1 to 2.2.6), Section 2.3 (2.3.12 to 2.3.13(iv))].

Weeks 9 to 11: Continuous mappings, Sequential and other characterizations of continuity, Uniform continuity, Homeomorphism, Contraction mappings, Banach fixed point theorem.

[1] Chapter 3 [Section 3.1, Section 3.4 (3.4.1 to 3.4.8), Section 3.5 (3.5.1 to 3.5.7(iii)), and Section 3.7 (3.7.1 to 3.7.5)].

Weeks 12 to 14: Connectedness and compactness, Definitions and properties of connected and compact spaces.

[1] Chapter 4 [Section 4.1 (4.1.1 to 4.1.12)], and Chapter 5 [Section 5.1 (5.1.1 to 5.1.6), and Section 5.3 (5.3.1 to 5.3.10)].

Facilitating the Achievement of Course Learning Outcomes

Unit No.	**Course Learning Outcomes**	**Teaching and Learning Activity**	**Assessment Tasks**
1.	Learn various natural and abstract formulations of distance on the sets of usual or unusual entities. Become aware one such formulations leading to metric spaces. Analyse how a theory advances from a particular frame to a general frame.	(i) Each topic to be explained with examples. (ii) Students to be involved in discussions and encouraged to ask questions. (iii) Students to be given homework/assignment. (iv) Students to be encouraged to give short presentations. (v) Illustrate the concepts through CAS.	• Student presentations • Participation in discussions. • Assignments and class tests. • Mid-term examinations. • End-term examinations.
2.	Appreciate the mathematical understanding of various geometrical concepts, viz. balls or connected sets etc. in an abstract setting.		
3.	Know about Banach fixed point theorem, whose far-reaching consequences resulted into an independent branch of study in analysis, known as fixed point theory.		
4.	Learn about the two important topological properties, namely connectedness and compactness of metric spaces.		

Keywords: Banach fixed point theorem, Cantor's theorem, Closure, Compactness, Connectedness, Contraction mapping, Interior, Open set.

BMATH512: Group Theory-II

Total Marks: 100 (Theory: 75, Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination**: 3 Hrs.

Course Objectives: The course will develop an in-depth understanding of one of the most important branch of the abstract algebra with applications to practical real-world problems. Classification of all finite abelian groups (up to isomorphism) can be done.

Course Learning Outcomes: The course shall enable students to:

i) Learn about automorphisms for constructing new groups from the given group.
ii) Learn about the fact that external direct product applies to data security and electric circuits.
iii) Understand fundamental theorem of finite abelian groups.
iv) Be familiar with group actions and conjugacy in S_n.
v) Understand Sylow theorems and their applications in checking nonsimplicity.

Unit 1: Automorphisms and Properties
Automorphism, inner automorphism, Automorphism groups, Automorphism groups of finite and infinite cyclic groups, Characteristic subgroups, Commutator subgroup and its properties; Applications of factor groups to automorphism groups.

Unit 2: External and Internal Direct Products of Groups
External direct products of groups and its properties, The group of units modulo n as an external direct product, Applications to data security and electric circuits; Internal direct products, Classification of groups of order p^2, where p is a prime; Fundamental theorem of finite abelian groups and its isomorphism classes.

Unit 3: Group Action
Group actions and permutation representations; Stabilizers and kernels of group actions; Groups acting on themselves by left multiplication and consequences; Conjugacy in S_n.

Unit 4: Sylow Theorems and Applications
Conjugacy classes, Class equation, p-groups, Sylow theorems and consequences, Applications of Sylow theorems; Finite simple groups, Nonsimplicity tests; Generalized Cayley's theorem, Index theorem, Embedding theorem and applications. Simplicity of A_5.

References:

1. Dummit, David S., & Foote, Richard M. (2016). *Abstract Algebra* (3rd ed.). Student Edition. Wiley India.
2. Gallian, Joseph. A. (2013). *Contemporary Abstract Algebra* (8th ed.). Cengage Learning India Private Limited. Delhi. Fourth impression, 2015.

Additional Reading:

i. Rotman, Joseph J. (1995). *An Introduction to The Theory of Groups* (4th ed.). Springer-Verlag, New York.

Teaching Plan (BMATH512: Group Theory-II):

Week 1: Automorphism, Inner automorphism, Automorphism groups, Automorphism groups of finite and infinite cyclic groups.

[2] Chapter 6 (Pages 135 to 138).

Week 2: Characteristic subgroups, Commutator subgroup and its properties; Applications of factor groups to automorphism groups.

[2] Exercises 1 to 4 on Page 181, and Exercises 62, 68 on Page 204.

[2] Chapter 9 (Theorem 9.4 and Example 17).

Week 3: External direct products of groups and its properties, The group of units modulo n as an external direct product, Applications to data security and electric circuits.

[2] Chapter 8.

Week 4: Internal direct products, Classification of groups of order p^2, where p is a prime.

[2] Chapter 9 (Section on internal direct products, Pages 195 to 200).

Week 5: Statement of the Fundamental theorem of finite abelian groups, The isomorphism classes of Abelian groups.

[2] Chapter 11.

Weeks 6 and 7: Group actions and permutation representations; Stabilizers and kernels of group actions.

[1] Chapter 1 (Section 1.7), Chapter 2 (Section 2.2) and Chapter 4 (Section 4.1, except cycle decompositions).

Weeks 8 and 9: Groups acting on themselves by left multiplication and consequences; Conjugacy in S_n.

[1] Chapter 4 [Section 4.2 and Section 4.3 (Pages 125-126)].

Week 10: Conjugacy classes, Class equation, p-groups.

[2] Chapter 24 (Pages 409 to 411).

Weeks 11 and 12: State three Sylow theorems and give their applications.

[2] Chapter 24 (Pages 412 to 421).

Weeks 13 and 14: Finite simple groups, Nonsimplicity tests; Generalized Cayley's theorem, Index theorem, Embedding theorem and applications; Simplicity of A_5.

[2] Chapter 25.

Facilitating the Achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
1.	Learn about automorphisms for constructing new groups from the given group. Learn about the fact that external direct product applies to data security and electric circuits.	(i) Each topic to be explained with examples. (ii) Students to be involved in discussions and encouraged to ask questions. (iii) Students to be given homework/assignments. (iv) Students to be encouraged to give short presentations.	• Presentations and participation in discussions. • Assignments and class tests. • Mid-term examinations. • End-term examinations.
2.	Understand fundamental theorem of finite abelian groups.		
3.	Be familiar with group actions and conjugacy in S_n.		
4.	Understand Sylow theorems and their applications in checking nonsimplicity.		

Keywords: Automorphism, External direct products, Isomorphism classes, Group action, Class equation, Sylow theorems.

Discipline Specific Elective (DSE) Course -1 (including practicals)

Any *one* of the following (at least *two* shall be offered by the college):

DSE-1 (i): Numerical Analysis
DSE-1 (ii): Mathematical Modeling and Graph Theory
DSE-1 (iii): C++ Programming for Mathematics

DSE-1 (i): Numerical Analysis

Total Marks: 150 (Theory: 75 + Internal Assessment: 25 + Practical: 50)
Workload: 4 Lectures, 4 Periods practical (per week) **Credits:** 6 (4+2)
Duration: 14 Weeks (56 Hrs. Theory + 56 Hrs. practical) **Examination:** 3 Hrs.

Course Objectives: To comprehend various computational techniques to find approximate value for possible root(s) of non-algebraic equations, to find the approximate solutions of system of linear equations and ordinary differential equations. Also, the use of Computer Algebra System (CAS) by which the numerical problems can be solved both numerically and analytically, and to enhance the problem solving skills.

Course Learning Outcomes: The course will enable the students to:

i) Learn some numerical methods to find the zeroes of nonlinear functions of a single variable and solution of a system of linear equations, up to a certain given level of precision.
ii) Know about methods to solve system of linear equations, such as Gauss–Jacobi, Gauss–Seidel and SOR methods.
iii) Interpolation techniques to compute the values for a tabulated function at points not in the table.
iv) Applications of numerical differentiation and integration to convert differential equations into difference equations for numerical solutions.

Unit 1: Methods for Solving Algebraic and Transcendental Equations
Algorithms, Convergence, Bisection method, False position method, Fixed point iteration method, Newton's method and Secant method.

Unit 2:Techniques to Solve Linear Systems
Partial and scaled partial pivoting, LU decomposition and its applications, Iterative methods: Gauss–Jacobi, Gauss–Seidel and SOR methods.

Unit 3: Interpolation
Lagrange and Newton interpolation, Piecewise linear interpolation.

Unit 4: Numerical Differentiation and Integration
First and higher order approximation for first derivative, Approximation for second derivative, Richardson extrapolation method; Numerical integration by closed Newton–Cotes formulae**:** Trapezoidal rule, Simpson's rule and its error analysis; Euler's method to solve ODE's, Second order Runge–Kutta Methods**:** Modified Euler's method, Heun's method and optimal RK2 method.

Note: Emphasis is to be laid on the algorithms of the above numerical methods. Non programmable scientific calculator may be allowed in the University examination.

Reference:

1. Bradie, Brian. (2006). *A Friendly Introduction to Numerical Analysis*. Pearson Education, India. Dorling Kindersley (India) Pvt. Ltd. Third impression 2011.

Additional Readings:

i. Jain, M. K., Iyengar, S. R. K., & Jain, R. K. (2012). *Numerical Methods for Scientific and Engineering Computation*. (6th ed.). New Age International Publisher, India, 2016.

ii. Gerald, C. F., & Wheatley, P. O. (2008). *Applied Numerical Analysis* (7th ed.). Pearson Education. India.

Practical / Lab work to be performed in Computer Lab:

Use of computer algebra software (CAS), for example Mathematica/MATLAB/Maple/ Maxima/Scilab etc., for developing the following numerical programs:

1. Bisection method
2. Newton–Raphson method
3. Secant method
4. Regula–Falsi method
5. LU decomposition method
6. Gauss–Jacobi method
7. SOR method
8. Gauss–Seidel method
9. Lagrange interpolation
10. Newton interpolation
11. Trapezoidal rule
12. Simpson's rule
13. Euler's method
14. Second order Runge–Kutta methods.

Note: For any of the CAS: Mathematica /MATLAB/ Maple/Maxima/Scilab etc., data types-simple data types, floating data types, character data types, arithmetic operators and operator precedence, variables and constant declarations, expressions, input/output, relational operators, logical operators and logical expressions, control statements and loop statements, Arrays should be introduced to the students.

Teaching Plan (Theory of DSE-l (i): Numerical Analysis):

Week 1: Algorithms, Convergence, Order of convergence and examples.
[1] Chapter 1 (Sections 1.1 and 1.2).

Week 2: Bisection method, False position method and their convergence analysis, Stopping condition and algorithms.
[1] Chapter 2 (Sections 2.1 and 2.2).

Week 3: Fixed point iteration method, its order of convergence and stopping condition.
[1] Chapter 2 (Section 2.3).

Week 4: Newton's method, Secant method, their order of convergence and convergence analysis.
[1] Chapter 2 (Sections 2.4 and 2.5).

Week 5: Examples to understand partial and scaled partial pivoting. LU decomposition.
[1] Chapter 3 (Sections 3.2, and 3.5 up to Example 3.15).
Weeks 6 and 7: Application of LU decomposition to solve system of linear equations. Gauss–Jacobi method, Gauss–Seidel and SOR iterative methods to solve system of linear equations.
[1] Chapter 3 (Sections 3.5 and 3.8).
Week 8: Lagrange interpolation**:** Linear and higher order interpolation, and error in it.
[1] Chapter 5 (Section 5.1).
Weeks 9 and 10: Divided difference and Newton interpolation, Piecewise linear interpolation.
[1] Chapter 5 (Sections 5.3 and 5.5).
Weeks 11 and 12: First and higher order approximation for first derivative and error in the approximation. Second order forward, Backward and central difference approximations for second derivative, Richardson extrapolation method
[1] Chapter 6 (Sections 6.2 and 6.3).
Week 13: Numerical integration**:** Trapezoidal rule, Simpson's rule and its error analysis.
[1] Chapter 6 (Section 6.4).
Week 14: Euler's method to solve ODE's, Second order Runge–Kutta methods**:** Modified Euler's method, Heun's method and optimal RK2 method.
[1] Chapter 7 (Section 7.2 up to Page 562 and Section 7.4, Pages 582-585).

Facilitating the achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
1.	Learn some numerical methods to find the zeroes of nonlinear functions of a single variable and solution of a system of linear equations, up to a certain given level of precision.	(i) Each topic to be explained with illustrations. (ii) Students be encouraged to discover the relevant concepts. (iii) Students to be given homework/assignments. (iv) Discuss and solve the theoretical and practical problems in the class. (v) Students to be encouraged to apply concepts to real world problems.	• Presentations and class discussions. • Assignments and class tests. • Student presentations. • Mid-term examinations. • Practical and viva-voce examinations. • End-term examinations.
2.	Know about methods to solve system of linear equations, such as Gauss–Jacobi, Gauss–Seidel and SOR methods.		
3.	Interpolation techniques to compute the values for a tabulated function at points not in the table.		
4.	Applications of numerical differentiation and integration to convert differential equations into difference equations for numerical solutions.		

Keywords: Algorithm, Euler's method, Interpolation, Iterative methods, LU decomposition, Newton–Cotes formulae, Order of convergence, Order of a method, Partial pivoting.

DSE-1 (ii): Mathematical Modeling and Graph Theory

Total Marks: 150 (Theory: 75 + Internal Assessment: 25 + Practical: 50)
Workload: 4 Lectures, 4 Periods practical (per week) **Credits:** 6 (4+2)
Duration: 14 Weeks (56 Hrs. Theory + 56 Hrs. practical) **Examination:** 3 Hrs.

Course Objectives: The main objective of this course is to teach students how to model physical problems using differential equations and solve them. Also, the use of Computer Algebra Systems (CAS) by which the listed problems can be solved both numerically and analytically.

Course Learning Outcomes: The course will enable the students to:

i) Know about power series solution of a differential equation and learn about Legendre's and Bessel's equations.
ii) Use of Laplace transform and inverse transform for solving initial value problems.
iii) Learn about various models such as Monte Carlo simulation models, queuing models, and linear programming models.
iv) Understand the basics of graph theory and learn about social networks, Eulerian and Hamiltonian graphs, diagram tracing puzzles and knight's tour problem.

Unit 1: Power Series Solutions
Power series solution of a differential equation about an ordinary point, Solution about a regular singular point, The method of Frobenius, Legendre's and Bessel's equations.

Unit 2: Laplace Transforms
Laplace transform and inverse transform, Application to initial value problem up to second order.

Unit 3: Monte Carlo Simulation
Monte Carlo simulation modeling**:** Simulating deterministic behavior (area under a curve, volume under a surface); Generating random numbers**:** Middle square method, Linear congruence; Queuing models**:** Harbor system, Morning rush hour; Overview of optimization modeling; Linear programming model: Geometric solution, Algebraic solution, Simplex method, Sensitivity analysis.

Unit 4: Graph Theory
Graphs, Diagraphs, Networks and subgraphs, Vertex degree, Paths and cycles, Regular and bipartite graphs, Four cube problem, Social networks, Exploring and traveling, Eulerian and Hamiltonian graphs, Applications to dominoes, Diagram tracing puzzles, Knight's tour problem, Gray codes.

References:

1. Aldous, Joan M., & Wilson, Robin J. (2007). *Graphs and Applications*: *An Introductory Approach*. Springer. Indian Reprint.
2. Edwards, C. Henry, Penney, David E., & Calvis, David T. (2015). *Differential Equations and Boundary Value Problems*: *Computing and Modeling* (5th ed.). Pearson.
3. Giordano, Frank R., Fox, William P., & Horton, Steven B. (2014). *A First Course in Mathematical Modeling* (5th ed.). Brooks/Cole, Cengage Learning.

Practical / Lab work to be performed in Computer Lab:

Modeling of the following problems using Mathematica/MATLAB/Maple/Maxima/Scilab etc.

1. Plotting of Legendre polynomial for n = 1 to 5 in the interval [0, 1]. Verifying graphically that all the roots of $P_n(x)$ lie in the interval [0, 1].
2. Automatic computation of coefficients in the series solution near ordinary points.
3. Plotting of the Bessel's function of first kind of order 0 to 3.
4. Automating the Frobenius series method.
5. (i) Random number generation and then use it for one of the following:
    (a) Simulate area under a curve,
    (b) Simulate volume under a surface.
   (ii) Programming of either one of the queuing model:
    (a) Single server queue (e.g. Harbor system),
    (b) Multiple server queue (e.g. Rush hour).
   (iii) Programming of the Simplex method for 2 / 3 variables.

Teaching Plan (Theory of DSE-l (ii): Mathematical Modeling and Graph Theory):

Weeks 1 and 3: Power series solution of a differential equation about an ordinary point, Solution about a regular singular point. Legendre's equation. The method of Frobenius.
[2] Chapter 8 (Sections 8.1 to 8.3).

Week 4: Bessel's equation. Bessel's function of first kind.
[2] Chapter 8 [Section 8.5 up to Equation (19), Page 551)].

Weeks 5 and 6: Laplace transform and inverse transform, Application to initial value problem up to second order.
[2] Chapter 7 (Sections 7.1 to 7.3).

Weeks 7 and 8: Monte Carlo simulation modeling**:** Simulating deterministic behavior (area under a curve, volume under a surface), Generating random numbers**:** Middle square method, Linear congruence. Queuing models**:** Harbor system, Morning rush hour.
[3] Chapter 5 (Sections 5.1 to 5.2, and 5.5).

Weeks 9 and 10: Overview of optimization modeling, Linear programming model: Geometric solution, Algebraic solution, Simplex method, Sensitivity analysis.
[3] Chapter 7.

Weeks 11 and 12: Graphs, Diagraphs, Networks and subgraphs, Vertex degree, Paths and cycles, Regular and bipartite graphs, Four cube problem, Social networks.
[1] Chapter 1 (Section 1.1), and Chapter 2.

Weeks 13 and 14: Overview of optimization modeling, Linear Programming Model: Geometric solution, Algebraic solution, Simplex method, Sensitivity analysis.
[1] Chapter 3.

Note: [1] Chapter 1 (Section 1.1), Chapter 2 (Sections 2.1 to 2.4), Chapter 3 (Sections 3.1 to 3.3) are to be reviewed only. This is in order to understand the models on Graph Theory.

Facilitating the Achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
1.	Know about power series solution of a differential equation and learn about Legendre's and Bessel's equations.	(i) Each topic to be explained with illustrations. (ii) Students to be encouraged to discover the relevant	• Presentations and class discussions. • Assignments and

2.	Use of Laplace transform and inverse transform for solving initial value problems.	concepts. (iii) Students to be given homework/assignments. (iv) Discuss and solve the theoretical and practical problems in the class. (v) Students to be encouraged to apply concepts to real world problems.	class tests. • Student presentations. • Mid-term examinations. • Practical and viva-voce examinations. • End-term examinations.
3.	Learn about various models such as Monte Carlo simulation models, queuing models, and linear programming models.		
4.	Understand the basics of graph theory and learn about social networks, Eulerian and Hamiltonian graphs, diagram tracing puzzles and knight's tour problem.		

Keywords: Legendre's and Bessel's equations, Laplace transformm Monte Carlo simulation, Hamiltonian graphs.

DSE-1 (iii): C++ Programming for Mathematics

Total Marks: 150 (Theory: 75 + Internal Assessment: 25 + Practical: 50)
Workload: 4 Lectures, 4 Periods practical (per week) **Credits:** 6 (4+2)
Duration: 14 Weeks (56 Hrs. Theory + 56 Hrs. practical) **Examination:** 3 Hrs.

Course Objectives: This course introduces C++ programming in the idiom and context of mathematics and imparts a starting orientation using available mathematical libraries, and their applications.

Course Learning Outcomes: After completion of this paper, student will be able to:

i) Understand and apply the programming concepts of C++ which is important to mathematical investigation and problem solving.
ii) Learn about structured data-types in C++ and learn about applications in factorization of an integer and understanding Cartesian geometry and Pythagorean triples.
iii) Use of containers and templates in various applications in algebra.
iv) Use mathematical libraries for computational objectives.
v) Represent the outputs of programs visually in terms of well formatted text and plots.

Unit 1: C++ Essentials
Fundamentals of programming, Organization of logic flow in stored program model of computation, C++ as a general purpose programming language, Structure of a C++ program, Common compilers and IDE's, Basic data-types, Variables and literals in C++, Operators, Expressions, Evaluation precedence, and Type compatibility. Outline of program development in C++, Debugging and testing; Applications**:** Greatest common divisor, and Random number generation.

Unit 2: Working with Structured Data
Structured data-types in C++, Arrays and manipulating data in arrays with applications in factorization of an integer and finding Euler's totient; Objects and classes**:** Information hiding, Modularity, Constructors and Destructors, Methods and Polymorphism; Applications**:** Cartesian geometry using points (2 & 3-dimensional), and Pythagorean triples.

Unit 3: Working with Containers and Templates
Containers and Template Libraries**:** Sets, Iterators, Multisets, Vectors, Maps, Lists, Stacks and Queues; Applications**:** Basic set algebra, Modulo arithmetic, Permutations, and Polynomials.

Unit 4: Using Mathematical Libraries and Packages
Arbitrary precision arithmetic using the GMP package; Linear algebra**:** Two-dimensional arrays in C++ with applications in finding eigenvalues, eigenvectors, rank, nullity, and solving system of linear equations in matrices; Features of C++ for input/output and visualization**:** strings, streams, formatting method; Processing files in a batch, Command-line arguments, Visualization packages and their use in plots.

Reference:

1. Scheinerman, Edward (2006). *C++ for Mathematicians*: *An Introduction for Students and Professionals*. Chapman & Hall/CRC. Taylor & Francis Group, LLC.

Additional Readings:

i. Dale, Nell & Weems, Chip (2013). *Programming and Problem Solving with C++* (6th ed.). Comprehensive Edition. Jones & Bartlett Learning.
ii. Gottschling, Peter (2016). *Discovering Modern C++: An Intensive Course for Scientists, Engineers, and Programmers*. Addison-Wesley. Pearson Education, Inc.
iii. Josuttis, Nicolai M. (2012). *The C++ Standard Library: A Tutorial and Reference* (2nd ed.). Addison-Wesley. Pearson Education, Inc.
iv. Lippman, Stanley B. (2000). *Essential C++*. Addison-Wesley.
v. Stroustrup, Bjarne (2013). *The C++ Programming Language* (4th ed.). Addison-Wesley.

Practical / Lab work to be performed in Computer Lab:

A: Preparatory (Practical Sessions: 8 Hrs.)

1. Setting up of C++ programming environment on Linux/Windows/Mac-OS; gcc/g++/mingw/cc, Program-development methodology and use IDE's or other tools.
2. Demonstration of sample programs for
   (i) "Hello World"
   (ii) Sum of an arithmetic progression.
   (iii) Value of $\sin x$ using series expansion.
3. Finding/demonstrating:
   (i) Machine epsilon.
   (ii) Integer and float overflow/underflow.
   (iii) Iteration and selection based logic.
   (provide a list of 8-10 problems suitable to learners needs)

B: Evaluative:

Set-I: (Practical Sessions: 8 Hrs.)

1. Greatest common divisor (including Euclid's Method).
2. Random number generation (including a Monte Carlo Program).

Set-II: (Practical Sessions: 12 Hrs.)

1. Factorization of an integer, and Euler's totient.
2. Cartesian geometry using points (2 & 3-dimensional).
3. Pythagorean triples.

Set-III: (Practical Sessions: 16 Hrs.)

1. Basic set algebra.
2. Modulo arithmetic.
3. Permutations.
4. Polynomials.

Set-IV: (Practical Sessions: 12 Hrs.)

1. Arbitrary precision arithmetic using the GMP package.
2. Finding eigenvalues, eigenvectors, rank, nullity, and solving system of linear equations in matrices.
3. Plots (using the GNU plotutils package).

Note. Exception handling in lab-exercises (SET-I to IV), Comments/Documentation using Doxygen may be emphasized.

Teaching Plan (Theory of DSE-1 (iii) C++ Programming for Mathematics):

Week 1: Fundamentals of programming, Organization of logic flow in stored program model of computation, C++ as a general purpose programming language, Structure of a C++ program, Common compilers and IDE's, Basic data-types.

[1] Chapter 1, and Chapter 2 (Sections 2.1 to 2.3).

Week 2: Variables and literals in C++, Operators, Expressions, Evaluation precedence, and Type compatibility. Outline of program development in C++, Debugging and testing.

[1] Chapter 2 (Sections 2.4 to 2.9).

Weeks 3 and 4: Applications**:** Greatest common divisor, and Random number generation.

[1] Chapters 3 and 4.

Week 5: Structured data-types in C++, Arrays and manipulating data in arrays. Applications**:** Factorization of an integer, and Euler's totient.

[1] Chapter 5 (Sections 5.1 to 5.4).

Weeks 6 and 7: Objects and classes**:** Information hiding, Modularity, Constructors and destructors, Methods and polymorphism; Applications**:** Cartesian geometry using points (two and three dimensional), and Pythagorean triples.

[1] Chapters 6 and 7.

Weeks 8 and 9: Containers and template libraries**:** sets, iterators, multisets, vectors, maps, lists, stacks and queues with applications in basic set algebra.

[1] Sections 8.1 to 8.7 (8.7.1-8.7.3).

Weeks 10 and 11: Applications**:** modulo arithmetic, permutations, and polynomials.

[1] Chapter 9, Chapter 11 (Sections 11.1, and 11.2) and Chapter 12 (Sections 12.1 to 12.3).

Week 12: Arbitrary precision arithmetic using the GMP package; Linear algebra**:** Two-dimensional arrays in C++ with applications in finding eigenvalues, eigenvectors, rank, nullity, and solving system of linear equations in matrices.

[1] Chapter 13 [Sections 13.1, and 13.2 (13.2.1, 13.2.2)].

Weeks 13 and 14: Features of C++ for input/output & visualization**:** strings, streams, formatting methods, processing files in a batch, command-line arguments, visualization packages and plots.

[1] Chapter 14 [Sections 14.1 to 14.6, and 14.8 (14.8.1-14.8.3)].

Facilitating the Achievement of Course Learning Outcomes

<table>
<tr><th>Unit No.</th><th>Course Learning Outcomes</th><th>Teaching and Learning Activity</th><th>Assessment Tasks</th></tr>
<tr><td>1.</td><td>Understand and apply the programming concepts of C++ which is important to mathematical investigation and problem solving.</td><td rowspan="4">(i) Each topic to be explained with illustrations.
(ii) Students to be encouraged to discover the relevant concepts.
(iii) Students to be given homework/assignments.
(iv) Discuss and solve the theoretical and practical problems in the class.
(v) Students to be encouraged to apply concepts to real world problems.</td><td rowspan="4">• Presentations and class discussions.
• Assignments and class tests.
• Mid-term examinations.
• Viva-voce examinations.
• End-term examinations.</td></tr>
<tr><td>2.</td><td>Learn about structured data-types in C++ and learn about applications in factorization of an integer and understanding Cartesian geometry and Pythagorean triples.</td></tr>
<tr><td>3.</td><td>Use of containers and templates in various applications in algebra.</td></tr>
<tr><td>4.</td><td>Use mathematical libraries for computational objectives.
Represent the outputs of programs visually in terms of well formatted text and plots.</td></tr>
</table>

Keywords: Array, Class, Command-line Argument, Constructor, Containers, Data-type, Debugging, Destructor, Multiset, Map, Object, Polymorphism, Queue, Vector.

Discipline Specific Elective (DSE) Course - 2

Any *one* of the following (at least *two* shall be offered by the college):

DSE-2 (i): Probability Theory and Statistics
DSE-2 (ii): Discrete Mathematics
DSE-2 (iii): Cryptography and Network Security

DSE-2 (i): Probability Theory and Statistics

Total Marks: 100 (Theory: 75 + Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: To make the students familiar with the basic statistical concepts and tools which are needed to study situations involving uncertainty or randomness. The course intends to render the students to several examples and exercises that blend their everyday experiences with their scientific interests.

Course Learning Outcomes: This course will enable the students to:

i) Learn about probability density and moment generating functions.
ii) Know about various univariate distributions such as Bernoulli, Binomial, Poisson, gamma and exponential distributions.
iii) Learn about distributions to study the joint behavior of two random variables.
iv) Measure the scale of association between two variables, and to establish a formulation helping to predict one variable in terms of the other, i.e., correlation and linear regression.
v) Understand central limit theorem, which helps to understand the remarkable fact that**:** the empirical frequencies of so many natural populations, exhibit a bell-shaped curve, i.e., a normal distribution.

Unit 1: Probability Functions and Moment Generating Function
Sample space, Probability set function, Real random variables - Discrete and continuous, Cumulative distribution function, Probability mass/density functions, Transformations, Mathematical expectation, Moments, Moment generating function, Characteristic function.

Unit 2: Univariate Discrete and Continuous Distributions
Discrete distributions**:** Uniform, Bernoulli, Binomial, Negative binomial, Geometric and Poisson; Continuous distributions**:** Uniform, Gamma, Exponential, Chi-square, Beta and normal; Normal approximation to the binomial distribution.

Unit 3: Bivariate Distribution
Joint cumulative distribution function and its properties, Joint probability density function, Marginal distributions, Expectation of function of two random variables, Joint moment generating function, Conditional distributions and expectations.

Unit 4: Correlation, Regression and Central Limit Theorem
The Correlation coefficient, Covariance, Calculation of covariance from joint moment generating function, Independent random variables, Linear regression for two variables, Method of least squares, Bivariate normal distribution, Chebyshev's theorem, Strong law of large numbers, Central limit theorem and weak law of large numbers.

References:

1. Hogg, Robert V., McKean, Joseph W., & Craig, Allen T. (2013). *Introduction to Mathematical Statistics* (7th ed.). Pearson Education, Inc.
2. Miller, Irwin & Miller, Marylees. (2014). John E. Freund's *Mathematical Statistics with*
   Applications (8th ed.). Pearson. Dorling Kindersley (India).
3. Ross, Sheldon M. (2014). *Introduction to Probability Models* (11th ed.). Elsevier Inc.

Additional Reading:

i. Mood, A. M., Graybill, F. A. & Boes, D. C. (1974). *Introduction to the Theory of Statistics* (3rd ed.). McGraw-Hill Education Pvt. Ltd. Indian Edition (2017).

Teaching Plan (DSE-2 (i): Probability Theory and Statistics):
Weeks 1 and 2: Sample space, Probability set function and examples, Random variable, Probability mass/density function, Cumulative distribution function and its properties.
[1] Chapter 1 (Sections 1.1, 1.3 and 1.5).
Week 3 and 4: Discrete and continuous random variables, and Transformations. Expectation of random variables, and some special expectations**:** Mean, Variance, Standard deviation, Moments and moment generating function, Characteristic function.
[1] Chapter 1 (Sections 1.6 to 1.9).
Week 5: The discrete distributions - Uniform, Bernoulli and binomial.
[2] Chapter 5 (Sections 5.2 to 5.4).
Week 6: The discrete distributions - negative Binomial, Geometric and Poisson.
[2] Chapter 5 (Sections 5.5 and 5.7).
Week 7: The continuous distributions - Uniform, Gamma, Exponential, Chi-square and Beta.
[2] Chapter 6 (Sections 6.2 to 6.4).
Week 8: Normal distribution, and normal approximation to the binomial distribution.
[2] Chapter 6 (Sections 6.5 and 6.6).
Weeks 9 and 10: Random vector**:** Discrete and continuous, Joint cumulative distribution function and its properties, Joint probability mass/density function, Marginal probability mass function, and expectation of two random variables, Joint moment generating function, Conditional distributions and expectations.
[1] Chapter 2 (Sections 2.1 and 2.3).
Week 11: Correlation coefficient, Covariance, Calculation of covariance from joint moment generating function, Independent random variables.
[1] Chapter 2 (Sections 2.4 and 2.5).
Week 12: Linear regression for two variables, and the method of least squares.
[2] Chapter 14 (Sections 14.1 to 14.3).
Week 13: Bivariate normal distribution; Chebyshev's theorem.
[2] Chapter 6 (Section 6.7), and Chapter 4 (Section 4.4).
Week 14: Statement and interpretation of the strong law of large numbers, Central limit theorem and the weak law of large numbers.
[3] Chapter 2 (Section 2.8, and Exercise 76, Page 89).

Facilitating the Achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
1.	Learn about probability density and moment generating functions.	(i) Each topic to be explained with examples. (ii) Students to be involved in discussions and encouraged to ask questions. (iii) Students to be given homework/ assignments. (iv) Students to be encouraged to give short presentations.	• Presentations and participation in discussions. • Assignments and class tests. • Mid-term examinations. • End-term examinations.
2.	Know about various univariate distributions such as Bernoulli, Binomial, Poisson, gamma and exponential distributions.		
3.	Learn about distributions to study the joint behavior of two random variables.		
4.	Measure the scale of association between two variables, and to establish a formulation helping to predict one variable in terms of the other, i.e., correlation and linear regression. Understand central limit theorem, which helps to understand the remarkable fact that: the empirical frequencies of so many natural populations, exhibit a bell-shaped curve, i.e., a normal distribution.		

Keywords: Chebyshev’s theorem, Correlation, Distributions, Distribution functions, Expectation, moments, Random variable, Regression.

DSE-2 (ii): Discrete Mathematics

Total Marks: 100 (Theory: 75 + Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: The course aims at introducing the concepts of ordered sets, lattices, sublattices and homomorphisms between lattices. It also includes introduction to modular and distributive lattices along with complemented lattices and Boolean algebra. Then some important applications of Boolean algebra are discussed in switching circuits. The second part of this course deals with introduction to graph theory, paths and circuits, Eulerian circuits, Hamiltonian graphs and finally some applications of graphs to shortest path algorithms.

Course Learning outcomes: After the course, the student will be able to:

i) Understand the notion of ordered sets and maps between ordered sets.
ii) Learn about lattices, modular and distributive lattices, sublattices and homomorphisms between lattices.
iii) Become familiar with Boolean algebra, Boolean homomorphism, Karnaugh diagrams, switching circuits and their applications.
iv) Learn about basics of graph theory, including Eulerian graphs, Hamiltonian graphs.
v) Learn about the applications of graph theory in the study of shortest path algorithms.

Unit 1: Ordered Sets
Definitions, Examples and basic properties of ordered sets, Order isomorphism, Hasse diagrams, Dual of an ordered set, Duality principle, Maximal and minimal elements, Building new ordered sets, Maps between ordered sets.

Unit 2: Lattices
Lattices as ordered sets, Lattices as algebraic structures, Sublattices, Products and homomorphisms; Definitions, Examples and properties of modular and distributive lattices, The $M_3 - N_5$ theorem with applications, Complemented lattice, Relatively complemented lattice, Sectionally complemented lattice.

Unit 3: Boolean Algebras and Switching Circuits
Boolean algebras, De Morgan's laws, Boolean homomorphism, Representation theorem; Boolean polynomials, Boolean polynomial functions, Disjunctive normal form and conjunctive normal form, Minimal forms of Boolean polynomial, Quine–McCluskey method, Karnaugh diagrams, Switching circuits and applications of switching circuits.

Unit 4: Graph Theory
Introduction to graphs, Königsberg bridge problem, Instant insanity game; Definition, examples and basic properties of graphs, Subgraphs, Pseudographs, Complete graphs, Bipartite graphs, Isomorphism of graphs, Paths and circuits, Eulerian circuits, Hamiltonian cycles, Adjacency matrix, Weighted graph, Travelling salesman problem, Shortest path, Dijkstra's algorithm.

References:

1. Davey, B. A., & Priestley, H. A. (2002). *Introduction to Lattices and Order* (2nd ed.). Cambridge University press, Cambridge.
2. Goodaire, Edgar G., & Parmenter, Michael M. (2011). *Discrete Mathematics with Graph Theory* (3rd ed.). Pearson Education (Singapore) Pvt. Ltd. Indian Reprint.
3. Lidl, Rudolf & Pilz, Gunter. (2004). *Applied Abstract Algebra* (2nd ed.), Undergraduate Texts in Mathematics. Springer (SIE). Indian Reprint.

Additional Reading:

i. Rosen, Kenneth H. (2012). *Discrete Mathematics and its Applications, with Combinatorics and Graph Theor*y. (7th ed.). McGraw-Hill Education. Indian Reprint.

Teaching Plan (DSE-2 (ii): Discrete Mathematics):

Weeks 1 and 2: Definitions, Examples and basic properties of ordered sets, Order isomorphism, Hasse diagrams, dual of an ordered set, Duality principle, Maximal and minimal elements, Building new ordered sets, Maps between ordered sets.

[1] Chapter 1 (Sections 1.1 to 1.5, Sections 1.14 to 1.26, and Sections 1.34 to 1.36).

[3] Chapter 1 [Section 1 (1.1 to 1.3)].

Weeks 3 and 4: Lattices as ordered sets, Lattices as algebraic structures, Sublattices, Products and homomorphisms.

[1] Chapter 2 (Sections 2.1 to 2.19).

[3] Chapter 1 [Section 1 (1.5 to 1.20)].

Week 5: Definitions, Examples and properties of Modular and distributive lattices.

[1] Chapter 4 (Sections 4.1 to 4.9).

[3] Chapter 1 [Section 2 (2.1 to 2.6).

Week 6: $M_3 - N_5$ theorem with applications, Complemented lattice, Relatively complemented lattice, Sectionally complemented lattice.

[1] Chapter 4 (Sections 4.10 and 4.11).

[3] Chapter 1 [Section 2 (2.7 to 2.14)].

Weeks 7 and 8: Boolean algebras, De Morgan’s laws, Boolean homomorphism, representation theorem, Boolean polynomials, Boolean polynomial functions, Disjunctive normal form and conjunctive normal form.

[3] Chapter 1 (Sections 3 and 4).

Week 9: Minimal forms of Boolean polynomial, Quine−McCluskey method, Karnaugh diagrams.

[3] Chapter 1 (Section 6).

Week 10: Switching circuits and applications of switching circuits.

[3] Chapter 2 (Sections 7 and 8).

Weeks 11 and 12: Introduction to graphs, Königsberg bridge problem, Instant insanity game. Definition, Examples and basic properties of graphs, Subgraphs, Pseudographs, Complete graphs, Bipartite graphs, Isomorphism of graphs.

[2] Chapter 9 [Sections 9.1, 9.2 (9.2.1, 9.2.7) and 9.3].

Weeks 13 and 14: Paths and circuits, Eulerian circuits, Hamiltonian cycles, Adjacency matrix, Weighted graph, Travelling salesman problem, shortest path, Dijkstra’s algorithm.

[2] Chapter 10 [Sections 10.1 to 10.4 (10.4.1 to 10.4.3)].

Facilitating the Achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
1.	Understand the notion of ordered sets and maps between ordered sets.	(i) Each topic to be explained with examples. (ii) Students to be involved in discussions and encouraged to ask questions. (iii) Students to be given homework/assignments. (iv) Students to be encouraged to give short presentations.	• Presentations and participation in discussions. • Assignments and class tests. • Mid-term examinations. • End-term examinations.
2.	Learn about lattices, modular and distributive lattices, sublattices and homomorphisms between lattices.		
3.	Become familiar with Boolean algebra, Boolean homomorphism, Karnaugh diagrams, switching circuits and their applications.		
4.	Learn about basics of graph theory, including Eulerian graphs, Hamiltonian graphs. Learn about the applications of graph theory in the study of shortest path algorithms.		

Keywords: Boolean algebra, Lattices, Graphs, Modularity, Ordered sets, Paths and circuits, Shortest path algorithms, Switching circuits.

DSE-2 (iii): Cryptography and Network Security

Total Marks: 100 (Theory: 75 + Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: This course helps the students to develop skills and knowledge of standard concepts in cryptography and demonstrates how cryptography plays an important role in the present digital world by knowing encryption and decryption techniques and secure data in transit across data networks.

Course Learning Outcomes: After the course, the student will be able to:

i) Understand the fundamentals of cryptography and computer security attacks.
ii) Learn about various ciphers and data encryption standard.
iii) Review basic concepts of number theory and finite fields.
iv) Learn about advanced encryption standard.
v) Understand the fundamentals of RSA and elliptic curve cryptography.
vi) Encrypt and decrypt messages using block ciphers, sign and verify messages using well known signature generation and verification algorithms.

Unit 1: Cryptography and Data Encryption Standard (DES)
Overview of Cryptography, Computer security concepts, Security attacks, Symmetric cipher model, Cryptanalysis and brute-force attack, Substitution techniques, Caesar cipher, Monoalphabetic ciphers, Playfair cipher, Hill cipher, Polyalphabetic ciphers, One-time pad, Transposition techniques, Binary and ASCII, Pseudo-random bit generation, Stream ciphers and Block ciphers, Feistal cipher, Data encryption standard (DES), DES example.

Unit 2: Algorithms and Advanced Encryption Standard (AES)
Review of basic concepts in Number theory and Finite Fields**:** divisibility, polynomial and modular arithmetic, Fermat's and Euler's theorems, Chinese remainder theorem, Discrete logarithm, Finite fields of the form GF(p) and GF(2^n); Advanced encryption standard (AES), AES transformation functions, AES key expansion, AES example.

Unit 3: Public-key Cryptography
Principles of public-key cryptosystems, RSA algorithm and security of RSA, Elliptic curve arithmetic, Elliptic curve cryptography, Cryptographic Hash functions, Secure Hash algorithm.

Unit 4: Digital Signatures and Network Security
Digital signatures, Elgamal and Schnorr digital signature schemes, Digital signature algorithm. Wireless network and mobile device security, Email architecture, formats, threats and security, Secure/Multipurpose Internet Mail Extension, Pretty Good Privacy.

References:

1. Stallings, William (2017). *Cryptography and Network Security*, *Principles and Practice* (7th ed.). Pearson Education Limited. England.
2. Trappe, Wade & Washington, Lawrence C. (2006). *Introduction to Cryptography with Coding Theory* (2nd ed.). Pearson Education International.

Additional Reading:

i. Stinson, Douglas R. (2005). *Cryptography Theory and Practice* (3rd ed.). CRC Press.

Teaching Plan (DSE-2 (iii): Cryptography and Network Security):

Weeks 1 and 2: Overview of Cryptography, Computer security concepts, Security attacks, Symmetric cipher model, Cryptanalysis and brute-force attack, Substitution techniques, Caesar cipher, Monoalphabetic ciphers, Playfair cipher, Hill cipher, Polyalphabetic ciphers, One-time pad.
[2] Chapter 1.
[1] Chapter 1 (Sections 1.1 and 1.3) and Chapter 3 (Sections 3.1 and 3.2).

Weeks 3 and 4: Transposition techniques, Binary and ASCII, Pseudo-random bit generation, Stream ciphers and Block ciphers, Feistal cipher, Data Encryption Standard (DES), DES example.
[1] Chapter 3 (Section 3.3) and Chapter 4 (Sections 4.1 to 4.3).
[2] Chapter 2 (Sections 2.8 and 2.10).

Weeks 5 and 6: Review of basic concepts in Number theory and Finite Fields: divisibility, polynomial and modular arithmetic, Statements of Fermat's and Euler's theorems, Chinese remainder theorem, Discrete logarithm, Finite fields of the form GF(p) and GF(2^n).
[1] Chapter 1 (Sections 2.1 to 2.3, 2.5, 2.7, and 2.8) and Chapter 5 (Sections 5.4 to 5.6).

Weeks 7 and 8: Advanced encryption standard (AES), AES transformation functions, AES key expansion, AES example.
[1] Chapter 6 [Sections 6.1 to 6.5 (up to Page 195)].

Weeks 9 and 10: Principles of public-key cryptosystems, RSA algorithm and security of RSA, Elliptic curve arithmetic, Elliptic curve cryptography.
[1] Chapter 9 (Sections 9.1 and 9.2), and Chapter 10 (Sections 10.3 and 10.4).

Week 11: Cryptographic Hash functions, Secure Hash algorithm.
[1] Sections 11.1 and 11.5.

Weeks 12 and 13: Digital signatures, Elgamal and Schnorr digital signature schemes, Digital signature algorithm, Wireless network and mobile device security.
[1] Chapter 13 (Sections 13.1 to 13.4) and Chapter 18 (Sections 18.1 and 18.2).

Week 14: Email architecture, threats and security, Secure/Multipurpose Internet Mail Extension (S/MIME) and Pretty Good Privacy (PGP).
[1] Chapter 19 [Sections 19.1 to 19.5 (Confidentiality excluded)].

Facilitating the Achievement of Course Learning Outcomes

<table>
<tr><th>Unit No.</th><th>Course Learning Outcomes</th><th>Teaching and Learning Activity</th><th>Assessment Tasks</th></tr>
<tr><td>1.</td><td>Understand the fundamentals of cryptography and computer security attacks.
Learn about various ciphers and data encryption standard.</td><td rowspan="4">(i) Each topic to be explained with examples.
(ii) Students to be involved in discussions and encouraged to ask questions.
(iii) Students to be given homework/ assignments.
(iv) Students to be encouraged to give short presentations.</td><td rowspan="4">• Student presentations.
• Participation in discussions.
• Assignments and class tests.
• Mid-term examinations.
• End-term examinations.</td></tr>
<tr><td>2.</td><td>Review basic concepts of number theory and finite fields.
Learn about advanced encryption standard.</td></tr>
<tr><td>3.</td><td>Understand the fundamentals of RSA and elliptic curve cryptography.</td></tr>
<tr><td>4.</td><td>Encrypt and decrypt messages using block ciphers, sign and verify messages using well known signature generation and verification algorithms.</td></tr>
</table>

Keywords: Cipher, Encryption, Hash function. Privacy, Public-key, Security.

Semester-VI

BMATH613: Complex Analysis

Total Marks: 150 (Theory: 75, Internal Assessment: 25 and Practical: 50)
Workload: 4 Lectures, 4 Practicals (per week), **Credits:** 6 (4+2)
Duration: 14 Weeks (56 Hrs. Theory + 56 Hrs. Practical) **Examination:** 3 Hrs.

Course Objectives: This course aims to introduce the basic ideas of analysis for complex functions in complex variables with visualization through relevant practicals. Emphasis has been laid on Cauchy's theorems, series expansions and calculation of residues.

Course Learning Outcomes: The completion of the course will enable the students to:
i) Learn the significance of differentiability of complex functions leading to the understanding of Cauchy–Riemann equations.
ii) Learn some elementary functions and valuate the contour integrals.
iii) Understand the role of Cauchy–Goursat theorem and the Cauchy integral formula.
iv) Expand some simple functions as their Taylor and Laurent series, classify the nature of singularities, find residues and apply Cauchy Residue theorem to evaluate integrals.

Unit 1: Analytic Functions and Cauchy–Riemann Equations
Functions of complex variable, Mappings; Mappings by the exponential function, Limits, Theorems on limits, Limits involving the point at infinity, Continuity, Derivatives, Differentiation formulae, Cauchy–Riemann equations, Sufficient conditions for differentiability; Analytic functions and their examples.

Unit 2: Elementary Functions and Integrals
Exponential function, Logarithmic function, Branches and derivatives of logarithms, Trigonometric function, Derivatives of functions, Definite integrals of functions, Contours, Contour integrals and its examples, Upper bounds for moduli of contour integrals,

Unit 3: Cauchy's Theorems and Fundamental Theorem of Algebra
Antiderivatives, Proof of antiderivative theorem, Cauchy–Goursat theorem, Cauchy integral formula; An extension of Cauchy integral formula, Consequences of Cauchy integral formula, Liouville's theorem and the fundamental theorem of algebra.

Unit 4: Series and Residues
Convergence of sequences and series, Taylor series and its examples; Laurent series and its examples, Absolute and uniform convergence of power series, Uniqueness of series representations of power series, Isolated singular points, Residues, Cauchy's residue theorem, residue at infinity; Types of isolated singular points, Residues at poles and its examples.

Reference:
1. Brown, James Ward, & Churchill, Ruel V. (2014). *Complex Variables and Applications* (9th ed.). McGraw-Hill Education. New York.

Additional Readings:

i. Bak, Joseph & Newman, Donald J. (2010). *Complex Analysis* (3rd ed.). Undergraduate Texts in Mathematics, Springer. New York.
ii. Zills, Dennis G., & Shanahan, Patrick D. (2003). *A First Course in Complex Analysis with Applications*. Jones & Bartlett Publishers, Inc.
iii. Mathews, John H., & Howell, Rusell W. (2012). *Complex Analysis for Mathematics and Engineering* (6th ed.). Jones & Bartlett Learning. Narosa, Delhi. Indian Edition.

Practical / Lab work to be performed in Computer Lab:

Modeling of the following similar problems using Mathematica/Maple/MATLAB/Maxima/ Scilab etc.

1. Make a geometric plot to show that the n^{th} roots of unity are equally spaced points that lie on the unit circle $C_1(0) = \{z : |z| = 1\}$ and form the vertices of a regular polygon with n sides, for $n = 4, 5, 6, 7, 8$.
2. Find all the solutions of the equation $z^3 = 8i$ and represent these geometrically.
3. Write parametric equations and make a parametric plot for an ellipse centered at the origin with horizontal major axis of 4 units and vertical minor axis of 2 units. Show the effect of rotation of this ellipse by an angle of $\frac{\pi}{6}$ radians and shifting of the centre from (0,0) to (2,1), by making a parametric plot.
4. Show that the image of the open disk $D_1(-1-i) = \{z : |z+1+i| < 1\}$ under the linear transformation $w = f(z) = (3 - 4i)z + 6 + 2i$ is the open disk: $D_5(-1 + 3i) = \{w: |w + 1 - 3i| < 5\}$.
5. Show that the image of the right half plane Re $z = x > 1$ under the linear transformation $w = (-1 + i)z - 2 + 3i$ is the half plane $v > u + 7$, where $u = \text{Re}(w)$, etc. Plot the map.
6. Show that the image of the right half plane A = $\{z : \text{Re}\, z \geq \frac{1}{2}\}$ under the mapping $w = f(z) = \frac{1}{z}$ is the closed disk $\overline{D_1(1)} = \{w : |w - 1| \leq 1\}$ in the w- plane.
7. Make a plot of the vertical lines $x = a$, for $a = -1, -\frac{1}{2}, \frac{1}{2}, 1$ and the horizontal lines $y = b$, for $b = -1, -\frac{1}{2}, \frac{1}{2}, 1$. Find the plot of this grid under the mapping $w = f(z) = \frac{1}{z}$.
8. Find a parametrization of the polygonal path $C = C_1 + C_2 + C_3$ from $-1 + i$ to $3 - i$, where C_1 is the line from: $-1 + i$ to -1, C_2 is the line from: -1 to $1 + i$ and C_3 is the line from $1 + i$ to $3 - i$. Make a plot of this path.
9. Plot the line segment 'L' joining the point $A = 0$ to $B = 2 + \frac{\pi}{4}i$ and give an exact calculation of $\int_L e^z dz$.
10. Plot the semicircle 'C' with radius 1 centered at $z = 2$ and evaluate the contour integral $\int_C \frac{1}{z-2} dz$.
11. Show that $\int_{C_1} z dz = \int_{C_2} z dz = 4 + 2i$ where C_1 is the line segment from $-1 - i$ to $3 + i$ and C_2 is the portion of the parabola $x = y^2 + 2y$ joining $-1 - i$ to $3 + i$. Make plots of two contours C_1 and C_2 joining $-1 - i$ to $3 + i$.

12. Use ML inequality to show that $\left|\int_C \frac{1}{z^2+1}dz\right| \le \frac{1}{2\sqrt{5}}$, where C is the straight line segment from 2 to $2 + i$. While solving, represent the distance from the point z to the points i and $-i$, respectively, i.e. $|z - i|$ and $|z + i|$ on the complex plane $\mathbb{C}$.
13. Show that $\int_C \frac{dz}{2z^{1/2}}$, where $z^{1/2}$ is the principal branch of the square root function and C is the line segment joining 4 to $8 + 6i$. Also plot the path of integration.
14. Find and plot three different Laurent series representations for the function $f(z) = \frac{3}{2+z-z^2}$, involving powers of z.
15. Locate the poles of $f(z) = \frac{1}{5z^4+26z^2+5}$ and specify their order.
16. Locate the zeros and poles of $g(z) = \frac{\pi\cot(\pi z)}{z^2}$ and determine their order. Also justify that $\text{Res}(g, 0) = -\pi^2/3$.
17. Evaluate $\int_{C_1^+(0)} \exp\left(\frac{2}{z}\right)dz$, where $C_1^+(0)$ denotes the circle $\{z : |z| = 1\}$ with positive orientation. Similarly evaluate $\int_{C_1^+(0)} \frac{1}{z^4+z^3-2z^2}dz$.

Note: For practicals: Sample materials of files in the form Mathematica/Maple 2011.zip, www.jblearning.com/catalog/9781449604455/.

Teaching Plan (Theory of BMATH613: Complex Analysis):

Week 1: Functions of complex variable, Mappings, Mappings by the exponential function.
[1] Chapter 2 (Sections 12 to 14).

Week 2: Limits, Theorems on limits, Limits involving the point at infinity, Continuity.
[1] Chapter 2 (Sections 15 to 18).

Week 3: Derivatives, Differentiation formulae, Cauchy-Riemann equations, Sufficient conditions for differentiability.
[1] Chapter 2 (Sections 19 to 22).

Week 4: Analytic functions, Examples of analytic functions, Exponential function.
[1] Chapter 2 (Sections 24 and 25) and Chapter 3 (Section 29).

Week 5: Logarithmic function, Branches and Derivatives of Logarithms, Trigonometric functions.
[1] Chapter 3 (Sections 30, 31 and 34).

Week 6: Derivatives of functions, Definite integrals of functions, Contours.
[1] Chapter 4 (Sections 37 to 39).

Week 7: Contour integrals and its examples, upper bounds for moduli of contour integrals.
[1] Chapter 4 (Sections 40, 41 and 43).

Week 8: Antiderivatives, proof of antiderivative theorem.
[1] Chapter 4 (Sections 44 and 45).

Week 9: State Cauchy–Goursat theorem, Cauchy integral formula.
[1] Chapter 4 (Sections 46 and 50).

Week 10: An extension of Cauchy integral formula, Consequences of Cauchy integral formula, Liouville's theorem and the fundamental theorem of algebra.
[1] Chapter 4 (Sections 51 to 53).

Week 11: Convergence of sequences, Convergence of series, Taylor series, proof of Taylor's theorem, Examples.
[1] Chapter 5 (Sections 55 to 59).

Week 12: Laurent series and its examples, Absolute and uniform convergence of power series, uniqueness of series representations of power series.
[1] Chapter 5 (Sections 60, 62, 63 and 66).

Week 13: Isolated singular points, Residues, Cauchy's residue theorem, Residue at infinity.

[1]: Chapter 6 (Sections 68 to 71).
Week 14: Types of isolated singular points, Residues at poles and its examples.
[1] Chapter 6 (Sections 72 to 74).

Facilitating the Achievement of Course Learning Outcomes

<table>
<tr><th>Unit No.</th><th>Course Learning Outcomes</th><th>Teaching and Learning Activity</th><th>Assessment Tasks</th></tr>
<tr><td>1.</td><td>Learn the significance of differentiability of complex functions leading to the understanding of Cauchy–Riemann equations.</td><td rowspan="4">(i) Each topic to be explained with illustrations.
(ii) Students to be encouraged to discover the relevant concepts.
(iii) Students to be given homework/assignments.
(iv) Discuss and solve the theoretical and practical problems in the class.
(v) Students be encouraged to apply concepts to real world problems.</td><td rowspan="4">• Presentations and class discussions.
• Assignments and class tests.
• Student presentations.
• Mid-term examinations.
• Practical and viva-voce examinations.
• End-term examinations.</td></tr>
<tr><td>2.</td><td>Learn some elementary functions and valuate the contour integrals.</td></tr>
<tr><td>3.</td><td>Understand the role of Cauchy–Goursat theorem and the Cauchy integral formula.</td></tr>
<tr><td>4.</td><td>Expand some simple functions as their Taylor and Laurent series, classify the nature of singularities, find residues and apply Cauchy Residue theorem to evaluate integrals.</td></tr>
</table>

Keywords: Analytic functions, Antiderivatives, Cauchy–Riemann equations, Cauchy–Goursat theorem, Cauchy integral formula, Cauchy's inequality, Cauchy's residue theorem, Closed contour, Contour integrals, Fundamental theorem of algebra, Liouville's theorem, Morera's theorem, Poles, Regions in complex plane, Residue, Singular points, Taylor's and Laurent's series.

BMATH614: Ring Theory and Linear Algebra-II

Total Marks: 100 (Theory: 75, Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: This course introduces the basic concepts of ring of polynomials and irreducibility tests for polynomials over ring of integers, used in finite fields with applications in cryptography. This course emphasizes the application of techniques using the adjoint of a linear operator and their properties to least squares approximation and minimal solutions to systems of linear equations.

Courses Learning Outcomes: On completion of this course, the student will be able to:

i) Appreciate the significance of unique factorization in rings and integral domains.
ii) Compute the characteristic polynomial, eigenvalues, eigenvectors, and eigenspaces, as well as the geometric and the algebraic multiplicities of an eigenvalue and apply the basic diagonalization result.
iii) Compute inner products and determine orthogonality on vector spaces, including Gram−Schmidt orthogonalization to obtain orthonormal basis.
iv) Find the adjoint, normal, unitary and orthogonal operators.

Unit 1: Polynomial Rings and Unique Factorization Domain (UFD)
Polynomial rings over commutative rings, Division algorithm and consequences, Principal ideal domains, Factorization of polynomials, Reducibility tests, Irreducibility tests, Eisenstein's criterion, Unique factorization in $\mathbb{Z}[x]$; Divisibility in integral domains, Irreducibles, Primes, Unique factorization domains, Euclidean domains.

Unit 2: Dual Spaces and Diagonalizable Operators
Dual spaces, Double dual, Dual basis, Transpose of a linear transformation and its matrix in the dual basis, Annihilators; Eigenvalues, Eigenvectors, Eigenspaces and characteristic polynomial of a linear operator; Diagonalizability, Invariant subspaces and Cayley−Hamilton theorem; Minimal polynomial for a linear operator.

Unit 3: Inner Product Spaces
Inner product spaces and norms, Orthonormal basis, Gram−Schmidt orthogonalization process, Orthogonal complements, Bessel's inequality.

Unit 4: Adjoint Operators and Their Properties
Adjoint of a linear operator, Least squares approximation, Minimal solutions to systems of linear equations, Normal, self-adjoint, unitary and orthogonal operators and their properties.

References:

1. Friedberg, Stephen H., Insel, Arnold J., & Spence, Lawrence E. (2003). *Linear Algebra* (4th ed.). Prentice-Hall of India Pvt. Ltd. New Delhi.
2. Gallian, Joseph. A. (2013). *Contemporary Abstract Algebra* (8th ed.). Cengage Learning India Private Limited. Delhi. Fourth impression, 2015.

Additional Readings:

i. Herstein, I. N. (2006). *Topics in Algebra* (2nd ed.). Wiley Student Edition. India.
ii. Hoffman, Kenneth, & Kunze, Ray Alden (1978). *Linear Algebra* (2nd ed.). Prentice-Hall of India Pvt. Limited. Delhi. Pearson Education India Reprint, 2015.

iii. Lang, Serge (1987). *Linear Algebra* (3rd ed.). Springer.

Teaching Plan (BMATH614: Ring Theory and Linear Algebra-II):

Week 1: Polynomial rings over commutative rings, Division algorithm and consequences, Principal ideal domains.
[2] Chapter 16.

Weeks 2 and 3: Factorization of polynomials, Reducibility tests, Irreducibility tests, Eisenstein's criterion, Unique factorization in $\mathbb{Z}[x]$.
[2] Chapter 17.

Weeks 4 and 5: Divisibility in integral domains, Irreducibles, Primes, Unique factorization domains, Euclidean domains.
[2] Chapter 18.

Week 6: Dual spaces, Double dual, Dual basis, Transpose of a linear transformation and its matrix in dual basis**,** Annihilators.
[1] Chapter 2 (Section 2.6).

Weeks 7 and 8: Eigenvalues, Eigenvectors, Eigenspaces and characteristic polynomial of a linear operator; Diagonalizability, Invariant subspaces and Cayley–Hamilton theorem; Minimal polynomial for a linear operator.
[1] Chapter 5 (Sections 5.1, 5.2 and 5.4), Chapter 7 (Section 7.3, Statement of Theorem 7.16)

Week 9: Inner product spaces and norms.
[1] Chapter 6 (Section 6.1).

Weeks 10 and 11: Orthonormal basis, Gram–Schmidt orthogonalization process, Orthogonal complements, Bessel's inequality.
[1] Chapter 6 (Section 6.2).

Week 12: Adjoint of a linear operator and its properties, Least squares approximation, Minimal solutions to systems of linear equations.
[1] Chapter 6 (Section 6.3, Statement of Theorem 6.13 with applications).

Weeks 13 and 14: Normal, self-adjoint, unitary and orthogonal operators and their properties.
[1] Chapter 6 (Sections 6.4, and 6.5, up to Theorem 6.21, Page 385).

Facilitating the Achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
1.	Appreciate the significance of unique factorization in rings and integral domains.	(i) Each topic to be explained with examples. (ii) Students to be involved in discussions and encouraged to ask questions. (iii) Students to be given homework/assignment. (iv) Students to be encouraged to give short presentations.	• Student presentations. • Participation in discussions. • Assignments and class tests. • Mid-term examinations. • End-term examinations.
2.	Compute the characteristic polynomial, eigenvalues, eigenvectors, eigenspaces, as well as the geometric and the algebraic multiplicities of an eigenvalue and apply the basic diagonalization result.		
3.	Compute inner products and determine orthogonality on vector spaces, including Gram–Schmidt orthogonalization to obtain orthonormal basis.		
4.	Find the adjoint, normal, unitary and orthogonal operators.		

Keywords: Bessel's inequality, Cayley–Hamilton theorem, Eigenvalues and eigenvectors, Eisenstein's criterion, Euclidean domains, Inner product spaces, Orthonormal basis, Principal ideal domains, Unique factorization domains, Normal, self-adjoint and unitary operators.

Discipline Specific Elective (DSE) Course - 3

Any *one* of the following (at least *two* shall be offered by the college):

DSE-3 (i): Mathematical Finance
DSE-3 (ii): Introduction to Information Theory and Coding
DSE-3 (iii): Biomathematics

DSE-3 (i): Mathematical Finance

Total Marks: 100 (Theory: 75 + Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: This course is an introduction to the application of mathematics in financial world, that enables the student to understand some computational and quantitative techniques required for working in the financial markets and actuarial mathematics.

Course Learning outcomes: On completion of this course, the student will be able to:

i) Know the basics of financial markets and derivatives including options and futures.
ii) Learn about pricing and hedging of options, as well as interest rate swaps.
iii) Learn about no-arbitrage pricing concept and types of options.
iv) Learn stochastic analysis (Ito formula, Ito integration) and the Black−Scholes model.
v) Understand the concepts of trading strategies and valuation of currency swaps.

Unit 1: Interest Rates

Interest rates, Types of rates, Measuring interest rates, Zero rates, Bond pricing, Forward rate, Duration, Convexity, Exchange traded markets and OTC markets, Derivatives--forward contracts, Futures contract, Options, Types of traders, Hedging, Speculation, Arbitrage.

Unit 2: Mechanics and Properties of Options

No Arbitrage principle, Short selling, Forward price for an investment asset, Types of options, Option positions, Underlying assets, Factors affecting option prices, Bounds on option prices, Put-call parity, Early exercise, Effect of dividends.

Unit 3: Stochastic Analysis of Stock Prices and Black-Scholes Model

Binomial option pricing model, Risk neutral valuation (for European and American options on assets following binomial tree model), Lognormal property of stock prices, Distribution of rate of return, expected return, Volatility, estimating volatility from historical data, Extension of risk neutral valuation to assets following GBM, Black−Scholes formula for European options.

Unit 4: Hedging Parameters, Trading Strategies and Swaps

Hedging parameters (the Greeks: Delta, Gamma, Theta, Rho and Vega), Trading strategies involving options, Swaps, Mechanics of interest rate swaps, Comparative advantage argument, Valuation of interest rate swaps, Currency swaps, Valuation of currency swaps.

Reference:

1. Hull, J. C., & Basu, S. (2010). *Options, Futures and Other Derivatives* (7th ed.). Pearson Education. New Delhi.

Additional Readings:

i. Luenberger, David G. (1998). *Investment Science*, Oxford University Press. Delhi.
ii. Ross, Sheldon M. (2011). *An elementary Introduction to Mathematical Finance* (3rd ed.). Cambridge University Press. USA.

Teaching Plan (DSE-3 (i): Mathematical Finance):

Weeks 1 and 2: Interest rates, Types of rates, Measuring interest rates, Zero rates, Bond pricing, Forward rate, Duration, Convexity.
[1] Chapter 4 (Section 4.1 to 4.4, 4.6, 4.8 and 4.9).
Weeks 3 and 4: Exchange traded markets and OTC markets, Derivatives- forward contracts, Futures contract, Options, Types of traders, Hedging, Speculation, Arbitrage**.**
[1] Chapter 1 (Sections 1.1 to 1.9).
Week 5: No Arbitrage principle, Short selling, Forward price for an investment asset.
[1] Chapter 5 (Sections 5.2 to 5.4).
Week 6: Types of options, Option positions, Underlying assets, Factors affecting option prices.
[1] Chapter 8 (Sections 8.1 to 8.3), and Chapter 9 (Section 9.1).
Week 7: Bounds on option prices, Put-call parity, Early exercise, Effect of dividends.
[1] Chapter 9 (Sections 9.2 to 9.7).
Week 8: Binomial option pricing model, Risk neutral valuation (for European and American options on assets following binomial tree model).
[1] Chapter 11 (Sections 11.1 to 11.5).
Weeks 9 to 11: Lognormal property of stock prices, Distribution of rate of return, expected return, Volatility, estimating volatility from historical data. Extension of risk neutral valuation to assets following GBM (without proof), Black–Scholes formula for European options.
[1] Chapter 13 (Sections 13.1 to 13.4, 13.7 and 13.8).
Week 12: Hedging parameters (the Greeks: Delta, Gamma, Theta, Rho and Vega).
[1] Chapter 17 (Sections 17.1 to 17.9).
Week 13: Trading strategies Involving options.
[1] Chapter 10 (except box spreads, calendar spreads and diagonal spreads).
Week 14: Swaps, Mechanics of interest rate swaps, Comparative advantage argument, Valuation of interest rate swaps, Currency swaps, Valuation of currency swaps
[1] Chapter 7 (Sections 7.1 to 7.4 and 7.7 to 7.9).

Facilitating the Achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
1.	Know the basics of financial markets and derivatives including options and futures. Learn about pricing and hedging of options, as well as interest rate swaps.	(i) Each topic to be explained with examples. (ii) Students to be involved in discussions and encouraged to ask questions. (iii) Students to be given homework/assignments. (iv) Students to be encouraged to give short presentations.	• Student presentations. • Participation in discussions. • Assignments and class tests. • Mid-term examinations. • End-term examinations.
2.	Learn about no-arbitrage pricing concept and types of options.		
3.	Learn stochastic analysis (Ito formula and Ito integration) and the Black–Scholes model.		
4.	Find the adjoint, normal, unitary and orthogonal operators.		

Keywords: Black–Scholes model, Forward contracts, Futures contract, Options, Hedging, Speculation, Arbitrage, Put-call parity, Short sellings, Swaps.

DSE-3 (ii): Introduction to Information Theory and Coding

Total Marks: 100 (Theory: 75, Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination**: 3 Hrs.

Course Objectives: This course aims to introduce the basic aspects of Information Theory and Coding to the students. Shannon's work form the underlying theme for the present course. Construction of finite fields and bounds on the parameters of a linear code discussed.

Course Learning Outcomes: This course will enable the students to:

i) Learn about the basic concepts of information theory.
ii) Know about basic relationship among different entropies and interpretation of Shannon's fundamental inequalities.
iii) Learn about the detection and correction of errors while transmission.
iv) Representation of a linear code by matrices.
v) Learn about encoding and decoding of linear codes.

Unit 1: Concepts of Information Theory
Communication processes, A model of communication system, A quantitative measure of information, Binary unit of information, A measure of uncertainty, H function as a measure of uncertainty, Sources and binary sources, Measure of information for two-dimensional discrete finite probability schemes.

Unit 2: Entropy Function
A sketch of communication network, Entropy, Basic relationship among different entropies, A measure of mutual information, Interpretation of Shannon's fundamental inequalities; Redundancy, Efficiency and channel capacity, Binary symmetric channel, Binary erasure channel, Uniqueness of the entropy function, Joint entropy and conditional entropy, Relative entropy and mutual information, Chain rules for entropy, Conditional relative entropy and conditional mutual information, Jensen's inequality and its characterizations, The log sum inequality and its applications.

Unit 3: Concepts of Coding
Block codes, Hamming distance, Maximum likelihood decoding, Levels of error handling, Error correction, Error detection, Erasure correction, Construction of finite fields, Linear codes, Matrix representation of linear codes.

Unit 4: Bounds of Codes
Orthogonality relation, Encoding of linear codes, Decoding of linear codes, Singleton bound and maximum distance separable codes, Sphere-packing bound and perfect codes, Gilbert−Varshamov bound, MacWilliams' identities.

References:

1. Cover, Thomas M., & Thomas, Joy A. (2006). *Elements of Information Theory* (2nd ed.). Wiley India. Indian Reprint 2014.
2. Gallian, Joseph. A. (2013). *Contemporary Abstract Algebra* (8th ed.). Cengage Learning India Private Limited. Delhi. Fourth impression, 2015.

3. Reza, Fazlollah M. (1961). *An Introduction to Information Theory*. Dover Publications Inc, New York. Reprint 1994.
4. Roth, Ron M. (2007). *Introduction to Coding Theory*. Cambridge University Press.

Additional Readings:

i. Ash, Robert B. (1965). *Information Theory*. Dover Publications, Inc. New York. Reprint in 1990.
ii. Goldman, Stanford (1968). *Information Theory*, Dover Publications, Inc. New York. Reprint in 1990.
iii. Ling, San & Xing, Chaoping (2004). *Coding Theory*: *A First Course*. Cambridge University Press.

Teaching Plan (DSE-3 (ii): Introduction to Information Theory and Coding):

Weeks 1 and 2: Communication processes, A model of communication system, A quantitative measure of information, Binary unit of information.

[3] Chapter 1 (Sections 1.1 to 1.7).

Weeks 3 and 4: A measure of uncertainty, H function as a measure of uncertainty, Sources and binary sources, Measure of information for two-dimensional discrete finite probability schemes.

[3] Chapter 3 (Sections 3.1 to 3.7).

Weeks 5 and 6: A sketch of communication network, Entropy, Basic relationship among different entropies, A measure of mutual information, Interpretation of Shannon's fundamental inequalities; redundancy, efficiency and channel capacity, Binary symmetric channel, Binary erasure channel, Uniqueness of the entropy function.

[3] Chapter 3 (Sections 3.9, 3.11 to 3.16 and 3.19).

[1] Chapter 2 (Section 2.1).

Weeks 7 and 8: Joint entropy and conditional entropy, Relative entropy and mutual information, Chain rules for entropy, Conditional relative entropy and conditional mutual information, Jensen's inequality and its characterizations, The log sum inequality and its applications.

[1] Chapter 2 (Sections 2.2 to 2.7).

Weeks 9 and 10: Block codes, Hamming distance, Maximum likelihood decoding, Levels of error handling, Error correction, Error detection, Erasure correction, Construction of finite fields.

[4] Chapter 1 (Sections 1.2 to 1.5, excluding 1.5.3), and Chapter 3 (Sections 3.1 to 3.4).

Weeks 11 and 12: Linear codes, Matrix representation of linear codes, Orthogonality relation, Encoding of linear codes, Decoding of linear codes.

[4] Chapter 2 (Sections 2.1 to 2.4).

[2] Chapter 31 (Lemma and Theorem 31.3 on Page 538).

Weeks 13 and 14: Singleton bound and maximum distance separable codes, Sphere-packing bound and perfect codes, Gilbert–Varshamov bound, MacWilliams' identities.

[4] Chapter 4 (Sections 4.1 to 4.4) and Chapter 11 (Section 11.1).

Facilitating the Achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
1.	Learn about the basic concepts of information theory.	(i) Each topic to be explained with examples. (ii) Students to be involved in discussions and encouraged to ask questions. (iii) Students to be given	• Student presentations. • Participation in discussions. • Assignments
2.	Know about basic relationship among different entropies and interpretation of Shannon's fundamental inequalities.		

3.	Learn about the detection and correction of errors while transmission.	homework/assignments. (iv) Students to be encouraged to give short presentations.	and class tests. • Mid-term examinations. • End-term examinations.
4.	Representation of a linear code by matrices. Learn about encoding and decoding of linear codes.		

Keywords: Measure of uncertainty, Entropy, Shannon's fundamental inequalities, Channel capacity, Linear codes, Gilbert–Varshamov bound.

DSE-3 (iii): Biomathematics

Total Marks: 100 (Theory: 75 + Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: The focus of the course is on scientific study of normal functions in living systems. The emphasis is on exposure to nonlinear differential equations with examples such as heartbeat, chemical reactions and nerve impulse transmission. The basic concepts of the probability to understand molecular evolution and genetics have also been applied.

Course Learning outcomes: Apropos conclusion of the course will empower the student to:

i) Learn the development, analysis and interpretation of bio mathematical models such as population growth, cell division, and predator-prey models.
ii) Learn about the mathematics behind heartbeat model and nerve impulse transmission model.
iii) Appreciate the theory of bifurcation and chaos.
iv) Learn to apply the basic concepts of probability to molecular evolution and genetics.

Unit 1: Modeling Biological Phenomenon
Population growth, Administration of drugs, Cell division, Systems of linear ordinary differential equations, Heartbeat, Nerve impulse transmission, Chemical reactions, Predator-prey models.

Unit 2: Mathematics of Heart Physiology and Nerve Impulse Transmission
Stability and oscillations**:** Epidemics, Phase plane and Jacobian matrix, Local stability, Stability, Limit cycles, Forced oscillations; Mathematics of heart physiology**:** local model, threshold effect, phase plane analysis and heartbeat model, A model of the cardiac pacemaker; Mathematics of nerve impulse transmission**:** excitability and repetitive firing, travelling waves.

Unit 3: Bifurcation and Chaos
Bifurcation, Bifurcation of a limit cycle, Discrete bifurcation and period-doubling, Chaos, Stability of limit cycles, Poincaré plane.

Unit 4: Modeling Molecular Evolution and Genetics
Modelling Molecular Evolution**:** Matrix models of base substitutions for DNA sequences, Jukes–Cantor model, Kimura models, Phylogenetic distances; Constructing Phylogenetic Trees**:** Phylogenetic trees, Unweighted pair-group method with arithmetic means (UPGMA), Neighbor joining method; Genetics**:** Mendelian genetics, Probability distributions in genetics.

References:

1. Allman, Elizabeth S., & Rhodes, John A. (2004). *Mathematical Models in Biology: An Introduction*. Cambridge University Press.
2. Jones, D. S., Plank, M. J., & Sleeman, B. D. (2009). *Differential Equations and Mathematical Biology* (2nd ed.). CRC Press, Taylor & Francis Group, LLC.

Additional Readings:

i. Murray, J. D. (2002). *An Introduction to Mathematical Biology* (3rd ed.). Springer.
ii. Myint-U, Tyn (1977). *Ordinary Differential Equations*. Elsevier North-Holland, Inc.
iii. Simmons, George F., & Krantz, Steven G. (2015). *Differential Equations*. McGraw-Hill Education. Indian Reprint.
iv. Strogatz, Steven H. (2009). *Nonlinear Dynamics and Chaos* (2nd ed.). Perseus Book Publishing. LLC. Sarat Publication, Kolkata, India.

Teaching Plan (DSE-3 (iii): Biomathematics):

Week 1: Population growth, Administration of drugs, Cell division, Systems of linear ordinary differential equations.
[2] Chapter 1 (Sections 1.1 to 1.3) and Chapter 3 (An overview of the methods in Sections 3.1 to 3.6).

Week 2: Heartbeat, Nerve impulse transmission.
[2] Chapter 4 (Sections 4.2, and 4.3).

Week 3: Chemical reactions, Predator-prey models, Epidemics (mathematical model).
[2] Chapter 4 (Sections 4.4 and 4.5) and Chapter 5 (Section 5.2)

Week 4: The phase plane and Jacobian matrix, Local stability.
[2] Chapter 5 (Sections 5.3 and 5.4).

Week 5: Stability, Limit cycles.
[2] Chapter 5 [Sections 5.5, and 5.6 (up to Page number 137)].

Week 6: Limit cycle criterion and Poincaré−Bendixson Theorem (interpretation only, with Example 5.6.1), Forced oscillations.
[2] Chapter 5 [Section 5.6 (Page number 137 to 138) and Section 5.7).

Week 7: Mathematics of heart physiology: local model, threshold effect, phase plane analysis and heartbeat model.
[2] Chapter 6 (Sections 6.1 to 6.3).

Week 8: A model of the cardiac pacemaker, Excitability and repetitive firing.
[2] Chapter 6 (Section 6.5) and Chapter 7 (Section 7.1).

Week 9: Travelling waves, Bifurcation, Bifurcation of a limit cycle.
[2] Chapter 7 (Section 7.2), and Chapter 13 (Sections 13.1 and 13.2).

Weeks 10 and 11: Discrete bifurcation and period-doubling, Chaos, Stability of limit cycles, Poincaré plane.
[2] Chapter 13 (Sections 13.3 to 13.6).

Week 12: Matrix models of base substitutions for DNA sequences, Jukes−Cantor model, Kimura models, Phylogenetic distances.
[1] Chapter 4 (Sections 4.4 and 4.5).

Week 13: Constructing phylogenetic trees: phylogenetic trees, unweighted pair-group method with arithmetic means (UPGMA), Neighbor joining method.
[1] Chapter 5 (Sections 5.1 to 5.3).

Week 14: Genetics**:** Mendelian genetics, probability distributions in genetics.
[1] Chapter 6 [Sections 6.1 and 6.2 (up to Equation 6.2 only)].

Facilitating the Achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
1.	Learn the development, analysis and interpretation of bio mathematical models such as	(i) Each topic to be explained with examples. (ii) Students to be involved in	• Student presentations.

	population growth, cell division, and predator-prey models.	discussions and encouraged to ask questions. (iii) Students to be given homework/assignments. (iv) Students to be encouraged to give short presentations.	• Participation in discussions. • Assignments and class tests. • Mid-term examinations. • End-term examinations.
2.	Learn about the mathematics behind heartbeat model and nerve impulse transmission model.		
3.	Appreciate the theory of bifurcation and chaos.		
4.	Learn to apply the basic concepts of probability to molecular evolution and genetics.		

Keywords: Bifurcation and chaos, Forced oscillations, Jukes–Cantor model, Kimura model, Limit cycles, Phase plane, Phylogenetic distances, Stability, UPGMA.

Discipline Specific Elective (DSE) Course - 4

Any *one* of the following (at least *two* shall be offered by the college):

DSE-4 (i): Number Theory
DSE-4 (ii): Linear Programming and Applications
DSE-4 (iii): Mechanics

DSE-4 (i): Number Theory

Total Marks: 100 (Theory: 75 and Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: In number theory there are challenging open problems which are comprehensible at undergraduate level, this course is intended to build a micro aptitude of understanding aesthetic aspect of mathematical instructions and gear young minds to ponder upon such problems. Also, another objective is to make the students familiar with simple number theoretic techniques, to be used in data security.

Course Learning Outcomes: This course will enable the students to:

i) Learn about some fascinating discoveries related to the properties of prime numbers, and some of the open problems in number theory, viz., Goldbach conjecture etc.
ii) Know about number theoretic functions and modular arithmetic.
iii) Solve linear, quadratic and system of linear congruence equations.
iv) Learn about public key crypto systems, in particular, RSA.

Unit 1: Distribution of Primes and Theory of Congruencies
Linear Diophantine equation, Prime counting function, Prime number theorem, Goldbach conjecture, Fermat and Mersenne primes, Congruence relation and its properties, Linear congruence and Chinese remainder theorem, Fermat's little theorem, Wilson's theorem.

Unit 2: Number Theoretic Functions
Number theoretic functions for sum and number of divisors, Multiplicative function, Möbius inversion formula, Greatest integer function. Euler’s phi-function and properties, Euler’s theorem.

Unit 3: Primitive Roots
The order of an integer modulo *n*, Primitive roots for primes, Composite numbers having primitive roots; Definition of quadratic residue of an odd prime, and Euler’s criterion.

Unit 4: Quadratic Reciprocity Law and Public Key Encryption
The Legendre symbol and its properties, Quadratic reciprocity, Quadratic congruencies with composite moduli; Public key encryption, RSA encryption and decryption.

References:

1. Burton, David M. (2012). *Elementary Number Theory* (7th ed.). Mc-Graw Hill Education Pvt. Ltd. Indian Reprint.

2. Jones, G. A., & Jones, J. Mary. (2005). *Elementary Number Theo*ry. Undergraduate Mathematics Series (SUMS). First Indian Print.

Additional Reading:

i. Neville Robinns. (2007). *Beginning Number Theory* (2nd ed.). Narosa Publishing House Pvt. Limited, Delhi.

Teaching Plan (DSE-4 (i): Number Theory):

Week 1: Linear Diophantine equation and its solutions, Distribution of primes, Prime counting function, Statement of the prime number theorem, Goldbach conjecture.
[1] Chapter 2 (Section 2.5).
[2] Chapter 2 (Section 2.2).

Week 2: Fermat and Mersenne primes, Congruence relation and its basic properties, Linear congruence equation and its solutions.
[2] Chapter 2 (Section 2.3).
[1] Chapter 4 (Sections 4.2 and 4.4).

Week 3: Chinese remainder theorem, to solve system of linear congruence for two variables, Fermat's little theorem, Wilson's theorem.
[1] Chapter 4 (Section 4.4), Chapter 5 (Section 5.2 up to before pseudo-prime at Page 90, Section 5.3).

Weeks 4 and 5: Number theoretic functions for sum and number of divisors, Multiplicative function, and the Möbius inversion formula. The greatest integer function, Euler's phi-function.
[1] Chapter 6 (Sections 6.1 to 6.2) and Chapter 7 (Section 7.2).

Week 6: Euler's theorem, Properties of Euler’s phi-function.
[1] Chapter 7 (Sections 7.3 and 7.4).

Weeks 7 and 8: The order of an integer modulo *n*. Primitive roots for primes.
[1] Chapter 8 (Sections 8.1 and 8.2).

Week 9: Composite numbers having primitive roots.
[1] Chapter 8 (Section 8.3).

Week 10: Definition of quadratic residue of an odd prime, and Euler's criterion.
[1] Chapter 9 (Section 9.1).

Weeks 11 and 12: The Legendre symbol and its properties. Quadratic reciprocity law.
[1] Chapter 9 (Section 9.2 up to Page 181 and Section 9.3).

Week 13: Quadratic congruencies with composite moduli.
[1] Chapter 9 (Section 9.4).

Week 14: Public key encryption, RSA encryption and decryption scheme.
[1] Section 10.1.

Facilitating the Achievement of Course Learning Outcomes

<table>
<tr><th>Unit No.</th><th>Course Learning Outcomes</th><th>Teaching and Learning Activity</th><th>Assessment Tasks</th></tr>
<tr><td>1.</td><td>Learn about some fascinating discoveries related to the properties of prime numbers, and some of the open problems in number theory, viz., Goldbach conjecture etc.</td><td rowspan="3">(i) Each topic to be explained with examples.
(ii) Students to be involved in discussions and encouraged to ask questions.
(iii) Students to be given homework/assignments.</td><td rowspan="3">• Student presentations.
• Participation in discussions.
• Assignments and class tests.
• Mid-term examinations.</td></tr>
<tr><td>2.</td><td>Know about number theoretic functions and modular arithmetic.</td></tr>
<tr><td>3.</td><td>Solve linear, quadratic and system of linear congruence equations.</td></tr>
</table>

4.	Learn about public key crypto systems, in particular, RSA.	(iv) Students to be encouraged to give short presentations.	• End-term examinations.

Keywords: Congruence, Decryption & Encryption, Legendre symbol, Multiplicative function, Prime numbers, Primitive roots, Reciprocity, Quadratic residue.

DSE-4 (ii): Linear Programming and Applications

Total Marks: 100 (Theory: 75 and Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: This course develops the ideas underlying the Simplex Method for Linear Programming Problem, as an important branch of Operations Research. The course covers Linear rogramming with applications to transportation, assignment and game problem. Such problems arise in manufacturing resource planning and financial sectors.

Course Learning Outcomes: This course will enable the students to:

i) Learn about the graphical solution of linear programming problem with two variables.
ii) Learn about the relation between basic feasible solutions and extreme points.
iii) Understand the theory of the simplex method used to solve linear programming problems.
iv) Learn about two-phase and big-M methods to deal with problems involving artificial variables.
v) Learn about the relationships between the primal and dual problems.
vi) Solve transportation and assignment problems.
vii) Apply linear programming method to solve two-person zero-sum game problems.

Unit 1: Introduction to Linear Programming
Linear programming problem**:** Standard, Canonical and matrix forms, Graphical solution; Convex and polyhedral sets, Hyperplanes, Extreme points; Basic solutions, Basic feasible solutions, Reduction of feasible solution to a basic feasible solution, Correspondence between basic feasible solutions and extreme points.

Unit 2: Methods of Solving Linear Programming Problem
Simplex method**:** Optimal solution, Termination criteria for optimal solution of the linear programming problem, Unique and alternate optimal solutions, Unboundedness; Simplex algorithm and its tableau format; Artificial variables, Two-phase method, Big-M method.

Unit 3: Duality Theory of Linear Programming
Motivation and formulation of dual problem; Primal-Dual relationships; Fundamental theorem of duality; Complimentary slackness.

Unit 4: Applications
*Transportation Problem***:** Definition and formulation; Methods of finding initial basic feasible solutions; Northwest-corner rule. Least- cost method; Vogel's approximation method; Algorithm for solving transportation problem.

*Assignment Problem***:** Mathematical formulation and Hungarian method of solving.

*Game Theory***:** Basic concept, Formulation and solution of two-person zero-sum games, Games with mixed strategies, Linear programming method of solving a game.

References:

1. Bazaraa, Mokhtar S., Jarvis, John J., & Sherali, Hanif D. (2010). *Linear Programming and Network Flows* (4th ed.). John Wiley and Sons.

2. Hadley, G. (1997). *Linear Programming*. Narosa Publishing House. New Delhi.
3. Taha, Hamdy A. (2010). *Operations Research*: *An Introduction* (9th ed.). Pearson.

Additional Readings:

i. Hillier, Frederick S. & Lieberman, Gerald J. (2015). *Introduction to Operations Research* (10th ed.). McGraw-Hill Education (India) Pvt. Ltd.
ii. Thie, Paul R., & Keough, G. E. (2014). *An Introduction to Linear Programming and Game Theory*. (3rd ed.). Wiley India Pvt. Ltd.

Teaching Plan (DSE-4 (ii): Linear Programming and Applications):

Week 1: Linear programming problem: Standard, Canonical and matrix forms, Graphical solution.
[1] Chapter 1 (Section 1.1).
[2] Chapter 1 (Sections 1.1 to 1.4 and 1.6).

Weeks 2 and 3: Convex and polyhedral sets, Hyperplanes, Extreme points; Basic solutions, Basic feasible solutions; Reduction of any feasible solution to a basic feasible solution; Correspondence between basic feasible solutions and extreme points.
[2] Chapter 2 (Sections 2.16, 2.19 and 2.20), and Chapter 3 (Sections 3.4 and 3.10).
[1] Chapter 3 (Section 3.2).

Week 4: Simplex Method: Optimal solution, Termination criteria for optimal solution of the linear programming problem, Unique and alternate optimal solutions, Unboundedness.
[1] Chapter 3 (Sections 3.3 and 3.6).

Weeks 5 and 6: Simplex algorithm and its tableau format.
[1] Chapter 3 (Sections 3.7 and 3.8).

Weeks 7 and 8: Artificial variables, Two-phase method, Big-M method.
[1] Chapter 4 (Sections 4.1 to 4.3).

Weeks 9 and 10: Motivation and formulation of dual problem; Primal-dual relationships.
[1] Chapter 6 (Section 6.1 and 6.2, up to Example 6.4).

Week 11: Statements of the fundamental theorem of duality and complimentary slackness theorem with examples.
[1] Chapter 6 (Section 6.2).

Weeks 12 and 13: Transportation problem, Assignment problem.
[3] Chapter 5 (Sections 5.1, 5.3 and 5.4).

Week 14: Game Theory**:** Basic concept, Formulation and solution of two-person zero-sum games, Games with mixed strategies, Linear programming method of solving a game.
[2] Chapter 11 (Sections 11.12 and 11.13).

Facilitating the Achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
1.	Learn about the graphical solution of linear programming problem with two variables. Learn about the relation between basic feasible solutions and extreme points.	(i) Each topic to be explained with examples. (ii) Students to be involved in discussions and encouraged to ask questions. (iii) Students to be given homework/assignments. (iv) Students to be encouraged to give short	• Student presentations. • Participation in discussions. • Assignments and class tests. • Mid-term examinations. • End-term examinations.
2.	Understand the theory of the simplex method used to solve linear programming problems. Learn about two-phase and big-M methods to deal with problems involving artificial variables.		

3.	Learn about the relationships between the primal and dual problems.	presentations.	
4.	Solve transportation and assignment problems. Apply linear programming method to solve two-person zero-sum game problems.		

Keywords: Artificial variables, Big-M method, Duality, Extreme points and basic feasible solutions, Simplex method, Two-phase method, Vogel's approximation method.

DSE-4 (iii): Mechanics

Total Marks: 100 (Theory: 75, Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination**: 3 Hrs.

Course Objectives: The course aims at understanding the various concepts of physical quantities and the related effects on different bodies using mathematical techniques. It emphasizes knowledge building for applying mathematics in physical world.

Course Learning Outcomes: The course will enable the students to:

i) Know about the concepts in statics such as moments, couples, equilibrium in both two and three dimensions.
ii) Understand the theory behind friction and center of gravity.
iii) Calculate moments of inertia of areas and rigid bodies.
iv) Know about conservation of mechanical energy and work-energy equations.
v) Learn about translational and rotational motion of rigid bodies.

Unit 1: Forces in Equilibrium
Coplanar force systems; Three-dimensional force systems; Moment of a force about a point and an axis, Principle of moments, Couple and couple moment, Moment of a couple about a line, Resultant of a force system, Distributed force system, Rigid-body equilibrium, Equilibrium of forces in two and three dimensions, Free-body diagrams, General equations of equilibrium, Constraints and statical determinacy.

Unit 2: Friction, Center of Gravity and Moments of Inertia
Equations of equilibrium and friction, Frictional forces on screws and flat belts; Center of gravity, Center of mass and Centroid of a body and composite bodies; Theorems of Pappus and Guldinus; Moments and products of inertia for areas, Composite areas and rigid body, Parallel-axis theorem, Moment of inertia of a rigid body about an arbitrary axis, Principal moments and principal axes of inertia.

Unit 3: Conservation of Energy and Applications
Conservative force fields, Conservation of mechanical energy, Work-energy equations, Kinetic energy and work-kinetic energy expressions based on center of mass, Moment of momentum equation for a single particle and a system of particles.

Unit 4: Rigid Body Motion
Translation and rotation of rigid bodies, Chasles' theorem, General relationship between time derivatives of a vector for different references, Relationship between velocities of a particle for different references, Acceleration of particle for different references.

References:

1. Hibbeler, R. C. (2016). *Engineering Mechanics*: *Statics & Dynamics* (14th ed.). Pearson Prentice Hall (Pearson Education), New Jersey.
2. Shames, Irving H., & Rao, G. Krishna Mohan (2009). *Engineering Mechanics*: *Statics and Dynamics* (4th ed.). Dorling Kindersley (India) Pvt. Ltd. (Pearson Education). Delhi.

Additional Reading:

i. Nelson, E. W., Best, Charles L. & McLean, W. G. (1998). *Theory and Problems of Engineering Mechanics*: *Statics and Dynamics* (5th ed.). McGraw-Hill, Schaum's Outline Series.

Teaching Plan (DSE-4 (iii): Mechanics):

Weeks 1 and 2: Coplanar force systems; Three-dimensional force systems. Moment of a force about a point and an axis, Principle of moments, Couple and couple moment, Moment of a couple about a line, Resultant of a force system, Distributed force system.
[1] Chapters 3 and 4.

Weeks 3 and 4: Rigid-body equilibrium, Equilibrium of forces in two and three dimensions, Free-body diagrams, General equations of equilibrium, Constraints and statical determinacy.
[1] Chapter 5.

Weeks 5 and 6: Equations of equilibrium and friction, Frictional forces on screws and flat belts; Center of gravity, Center of mass and Centroid of a body and composite bodies; Theorems of Pappus and Guldinus.
[1] Chapters 8 and 9.

Weeks 7 and 8: Moments and products of inertia for areas, Composite areas and rigid body, Parallel-axis theorem, Moment of inertia of a rigid body about an arbitrary axis, Principal moments and principal axes of inertia.
[1] Chapter 10 (Sections 10.1 to 10.5) and Chapter 21 (Section 21.1).

Weeks 9 to 11: Conservative force fields, Conservation of mechanical energy, Work-energy equations, Kinetic energy and work-kinetic energy expressions based on center of mass, Moment of momentum equation for a single particle and a system of particles.
[2] Chapter 11 and Chapter 12 (Sections 12.5 and 12.6).

Weeks 12 to 14: Translation and rotation of rigid bodies, Chasles' theorem, General relationship between time derivatives of a vector for different references, Relationship between velocities of a particle for different references, Acceleration of particle for different references.
[2] Chapter 13 (Sections 13.1 to 13.3, and 13.6 to 13.8).

Facilitating the Achievement of Course Learning Outcomes

Unit No.	Course Learning Outcomes	Teaching and Learning Activity	Assessment Tasks
1.	Know about the concepts in statics such as moments, couples, equilibrium in both two and three dimensions.	(i) Each topic to be explained with examples. (ii) Students to be involved in discussions and encouraged to ask questions. (iii) Students to be given homework/assignments. (iv) Students to be encouraged to give short presentations.	• Student presentations. • Participation in discussions. • Assignments and class tests. • Mid-term examinations. • End-term examinations.
2.	Understand the theory behind friction and center of gravity. Calculate moments of inertia of areas and rigid bodies.		
3.	Know about conservation of mechanical energy and work-energy equations.		
4.	Learn about translational and rotational motion of rigid bodies.		

Keywords: Center of gravity, Conservation of energy and its applications, Forces in equilibrium, Friction, Moments of inertia, Rigid body motion.

Acknowledgments

The following members were actively involved in drafting the LOCF syllabus of B.Sc. (Hons.) Mathematics, University of Delhi.

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Coordinator

- Hemant Kumar Singh, Department of Mathematics

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- Pankaj Garg (Rajdhani College)
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- Charanpreet Kaur (SGTB Khalsa College)

UNIVERSITY OF DELHI

BACHELOR OF SCIENCE (HONS.) IN MATHEMATICS

(B.Sc. (Hons.) Mathematics)

(Effective from Academic Year 20-- - --)

PROPOSED SYLLABUS

XXXXX Revised Syllabus as approved by Academic Council on XXXX, 2018 and

Executive Council on YYYY, 2018

CONTENTS

I. About the Department

The Department of Mathematics, University of Delhi took birth in 1947, with Prof. Ram Behari, an eminent Differential geometer, as Head of the Department. Several distinguished mathematicians have been part of the Department's long and successful journey so far, Prof. R. S. Varma and Prof. U.N. Singh among them. While research activities in Operations Research, Information Theory, Coding Theory, Space Dynamics and Complex Analysis blossomed under the former's leadership, the latter made the Department a very strong, global research hub for Functional Analysis, Operator Theory and Harmonic Analysis. As the activities of the Department grew exponentially, in 1973, the single department metamorphosed into the Faculty of Mathematical Sciences with four constituent departments: Mathematics, Operations Research, Statistics and Computer Science. The South Campus unit of the Department of Mathematics also came into being in 1973. The Department of Mathematics continues to uphold the high traditions of teaching and research which have shaped it from the very beginning.

The Mathematics Department offers a Masters programme in Mathematics besides two research programmes, the M.Phil. and Ph.D. in Mathematics. Nearly hundred students have been awarded Ph.D. degrees in the last five years. The department is also actively involved in administering the University's undergraduate programmes in Mathematics through constituent colleges of the University of Delhi. We are supported by grants from DST(FIST), DST(PURSE) and UGC-DRS(SAP). Our excellent and highly experienced faculty, with qualifications from premier institutions and expertise in diverse fields including Algebraic Geometry, Coding Theory, Complex Analysis, Commutative Algebra, Combinatorics, Control Theory, Differential Equations, Dynamical Systems, Ergodic Theory, Field Theory, Fluid Dynamics, Functional Analysis, Harmonic Analysis, Operator Theory, Operator Algebras, Optimization and Topology, has helped us in securing high positions in various national and international rankings. For example, we are ranked 10 in Times Higher Education Ranking in India and 144 in Asia in 2018. Several faculty members are or have been fellows of prestigious national science academies and recipients of awards of excellence from such academies. Many members are also actively involved as consultant/advisor for UGC, DST, CSIR, UPSC, Lok Sabha and are on advisory committees of several universities in the country.

The Bachelors programme, B.Sc. (Hons.) Mathematics aims to build strong foundations in core areas of higher mathematics in both the pure and applied areas. It is meant for students who would typically take up careers involving mathematical research or mathematical skills – in academia or in industry. The training imparted to the students helps them master the art of problem solving, developing logical reasoning and computational capabilities which are essential traits in all walks of life. Additionally, the knowledge of mathematical modeling and computational training which the students acquire during the programme makes them highly sought after. In keeping with the demands of industry and academia, the syllabus is updated regularly, with inputs taken from various stakeholders including students, alumni and parents at different stages of the preparation of the syllabus.

II. Introduction to CBCS (Choice Based Credit System)

Choice Based Credit System:

The CBCS provides an opportunity for the students to choose courses from the prescribed courses comprising core, elective/minor or skill-based courses. The courses can be evaluated following the grading system, which is considered to be better than the conventional marks system. Grading system provides uniformity in the evaluation and computation of the Cumulative Grade Point Average (CGPA) based on student's performance in examinations enables the student to move across institutions of higher learning. The uniformity in evaluation system also enable the potential employers in assessing the performance of the candidates.

Definitions:

(i) 'Academic Programme' means an entire course of study comprising its programme structure, course details, evaluation schemes etc. designed to be taught and evaluated in a teaching Department/Centre or jointly under more than one such Department/Centre.

(ii) 'Course' means a segment of a subject that is part of an Academic Programme.

(iii) 'Programme Structure' means a list of courses (Core, Elective, Open Elective) that makes up an Academic Programme, specifying the syllabus, Credits, hours of teaching, evaluation and examination schemes, minimum number of credits required for successful completion of the programme etc. prepared in conformity to University Rules, eligibility criteria for admission.

(iv) 'Core Course' means a course that a student admitted to a particular programme must successfully complete to receive the degree and which cannot be substituted by any other course.

(v) 'Elective Course' means an optional course to be selected by a student out of such courses offered in the same or any other Department/Centre.

(vi) 'Discipline Specific Elective (DSE)' Course is the domain specific elective course offered by the main discipline/subject of study. The University/Institute may also offer discipline related Elective courses of interdisciplinary nature also, but these are needed to be offered by main discipline/subject of study.

(vii) 'Dissertation/Project' is an elective course designed to acquire special/advanced knowledge, such as supplement study/support study to a project work, and a candidate studies such a course on his own with an advisory support by a teacher/faculty member. Project work/Dissertation is considered as a special course involving application of knowledge in solving /analysing /exploring a real life situation/difficult problem. A Project/Dissertation work would be of 6 credits. A Project/Dissertation work may be given in lieu of a discipline specific elective paper.

(viii) 'Generic Elective (GE)' Course is an elective course chosen generally from an unrelated discipline/subject, with an intention to seek exposure to other disciplines. A core course offered in a discipline/subject may be treated as an elective by other discipline/subject and vice versa and such electives may also be referred to as Generic Elective.

(ix) 'Ability Enhancement Courses (AEC)' also referred as Competency Improvement Courses/Skill Development Courses/Foundation Course. The Ability Enhancement Courses (AEC) may be of two kinds: AE Compulsory Course (AECC) and AE Elective Course (AEEC).

(x) 'AECC' are the courses based upon the content that leads to Knowledge enhancement. The two AECC are: Environmental Science, English/MIL Communication.

(xi) 'AEEC' are value-based and/or skill-based and are aimed at providing hands-on-training, competencies, skills, etc. These courses may be chosen from a pool of courses designed to provide value-based and/or skill-based instruction. These courses are also referred to as Skill Enhancement Courses (SEC).

(vii) 'Credit' means the value assigned to a course which indicates the level of instruction; One-hour lecture per week equals 1 Credit, 2 Hours practical class per week equals 1 credit. Credit for a practical could be proposed as part of a course or as a separate practical course

(viii) 'CGPA' is cumulative grade points calculated for all courses completed by the students at any point of time.

(ix) 'SGPA' means Semester Grade Point Average calculated for individual semester.

(x) 'CGPA' is Cumulative Grade Points Average calculated for all courses completed by the students at any point of time. CGPA is calculated each year for both the semesters clubbed together.

(xi) 'Grand CGPA' is calculated in the last year of the course by clubbing together of CGPA of two years, i.e., four semesters. Grand CGPA is being given in Transcript form. To benefit the student a formula for conversation of Grand CGPA into % age marks is given in the Transcript.

CBCS Course Structure for B.Sc. (Hons.) Mathematics Programme

Courses	*Credits Theory + Practical	*Credits Theory + Tutorial
I. Core Courses (14 Papers)	$14\times4 = 56$	$14\times5 = 70$
Core Course Practical / Tutorial* (14 Practicals/Tutorials*)	$14\times2 = 28$	$14\times1 = 14$
II. Elective Courses (8 Papers)		
A.1. Discipline Specific Elective (4 Papers)	$4\times4 = 16$	$4\times5 = 20$
A.2. Discipline Specific Elective Practical/ Tutorial* (4 Papers)	$4\times2 = 8$	$4\times1 = 4$
B.1. Generic Elective/ Interdisciplinary (4 Papers)	$4\times4 = 16$	$4\times5 = 20$
B.2. Generic Elective Practical/ Tutorial* (4 Papers)	$4\times2 = 8$	$4\times1 = 4$
III. Ability Enhancement Courses		
1. Ability Enhancement Compulsory Courses (AECC) (2 Papers of 4 credits each) Environmental Science English /MIL Communication	$2\times4 = 8$	$2\times4 = 8$
2. Ability Enhancement Elective (Skill Based) (Minimum 2) (SEC) (2 Papers of 4 credits each)	$2\times4 = 8$	$2\times4 = 8$
Total credits:	**148**	**148**

* **Wherever there is a practical there will be no tutorial and vice-versa**

SEMESTER WISE PLACEMENT OF THE COURSES

Semester	Core Course(14)	Ability Enhancement Compulsory Course (AECC)(2)	Skill Enhancement Course (SEC)(2)	Discipline Specific Elective (DSE)(4)	Generic Elective (GE)(4)
I	BMATH101: Calculus (including practicals) BMATH102: Algebra	(English Communication/MIL)/ Environmental Science			GE-1
II	BMATH203: Real Analysis BMATH204: Differential Equations(including practicals)	(English Communication/MIL)/ Environmental Science			GE-2
III	BMATH305: Theory of Real Functions BMATH306: Group Theory-I BMATH307: Multivariate Calculus (including practicals)		SEC-1 LaTeX and HTML		GE-3
IV	BMATH408: Partial Differential Equations (including practicals) BMATH409: Riemann Integration and Series of Functions BMATH410: Ring Theory and Linear Algebra-I		SEC-2 Computer Algebra Systems and Related Software		GE-4
V	BMATH511: Metric Spaces BMATH512: Group Theory-II			DSE-1 (including practicals) DSE-2	
VI	BMATH613: Complex Analysis (including practicals) BMATH614: Ring Theory and Linear Algebra-II			DSE-3 DSE-4	

III. B.Sc. (Hons.) Mathematics Programme Details:

Programme Objectives: Students who choose B.Sc. (Hons.) Mathematics Programme, develop the ability to think critically, logically and analytically and hence use mathematical reasoning in everyday life. Pursuing a degree in mathematics will introduce the students to a number of interesting and useful ideas in preparations for a number of mathematics careers in education, research, government sector, business sector and industry.

The programme covers the full range of mathematics, from classical Calculus to Modern Cryptography, Information Theory, and Network Security. The course lays a structured foundation of Calculus, Real & Complex analysis, Abstract Algebra, Differential Equations (including Mathematical Modeling), Number Theory, Graph Theory, and C++ Programming exclusively for Mathematics.

An exceptionally broad range of topics covering Pure & Applied Mathematics: Linear Algebra, Metric Spaces, Statistics, Linear Programming, Numerical Analysis, Mathematical Finance, Coding Theory, Mechanics and Biomathematics cater to varied interests and ambitions. Also hand on sessions in Computer Lab using various Computer Algebra Systems (CAS) softwares such as Mathematica, MATLAB, Maxima, **R** to have a deep conceptual understanding of the above tools are carried out to widen the horizon of students' self-experience.

To broaden the interest for interconnectedness between formerly separate disciplines one can choose from the list of Generic electives for example one can opt for economics as one of the GE papers. Skill enhancement Courses enable the student acquire the skill relevant to the main subject. Choices from Discipline Specific Electives provides the student with liberty of exploring his interests within the main subject.

Of key importance is the theme of integrating mathematical and professional skills. The well-structured programme empowers the student with the skills and knowledge leading to enhanced career opportunities in industry, commerce, education, finance and research.

Programme Learning Outcomes: The completion of the B.Sc. (Hons.) Mathematics Programme will enable a student to:

i) Communicate mathematics effectively by written, computational and graphic means.
ii) Create mathematical ideas from basic axioms.
iii) Gauge the hypothesis, theories, techniques and proofs provisionally.
iv) Utilize mathematics to solve theoretical and applied problems by critical understanding, analysis and synthesis.
v) Identify applications of mathematics in other disciplines and in the real-world, leading to enhancement of career prospects in a plethora of fields and research.

Programme Structure: The B.Sc. (Hons.) Mathematics programme is a three-year, six-semesters course. A student is required to complete 148 credits for completion of the course.

		Semester	**Semester**
Part – I	First Year	Semester I: 22	Semester II: 22
Part – II	Second Year	Semester III: 28	Semester IV: 28
Part - III	Third Year	Semester V: 24	Semester VI: 24

Teaching:

The faculty of the Department of Mathematics of the College is primarily responsible for organizing lecture work for B.Sc. (Hons.) Mathematics course. The instructions related to tutorials are provided by the respective registering units under the overall guidance of the department. Faculty from some other departments and constituent colleges are also associated with lecture and tutorial work in the department.

Teaching Pedagogy:

Teaching pedagogy involving class room interactions, discussion, presentation etc.

Eligibility for Admissions:

Senior Secondary School Certificate Examination (Class XII) of the Central Board of Secondary Education or an examination recognized as equivalent thereto.

50% marks in Mathematics and an aggregate of 45% marks in the qualifying examination. (Relaxation will be given to the candidates belonging SC, ST and OBC category as per the University rules).

Specific Requirements: The merit shall be determined on the basis of aggregate of marks obtained in Mathematics, one language paper and two best elective subjects under academic stream.

Assessment Tasks:

Comprising MCQs, Project work and presentations, design and production of course related objects, written assignments, open or closed book exams specifically designed to assess the Learning Outcomes.

Assessment of Students' Performance and Scheme of Examinations:

i) English shall be the medium of instruction and examination.

ii) Assessment of students' performance shall consist of:
(Point wise details of internal assessment and end semester examination, their weightage and scheme to be given)

It is mentioned along with course content of respective courses.

Pass Percentage & Promotion Criteria: As per University Examination rule.

Part to Part Progression: As per University Examination rule

Conversion of Marks into Grades: As per University Examination rule

Grade Points: Grade point table as per University Examination rule

CGPA Calculation: As per University Examination rule.

SGPA Calculation: As per University Examination rule

Grand SGPA Calculation: As per University Examination rule

Conversion of Grand CGPA into Marks

As per University Examination rule

Division of Degree into Classes:

As per University Examination rule

Attendance Requirement:

As per University Examination rule

Span Period:

No student shall be admitted as a candidate for the examination for any of the Parts/Semesters after the lapse of **five** years from the date of admission to the Part-I/Semester-I of the B.Sc. (Hons.) Mathematics programme.

Guidelines for the Award of Internal Assessment Marks B.Sc. (Hons.) Mathematics Programme (Semester Wise):

1. That 10 (5) maximum marks be assigned to House Examination /Class Test in each core and discipline specific elective (skill enhancement) paper.
2. That 10(5) maximum marks be assigned to written assignments & project reports/ seminars etc. in each core and discipline specific elective (skill enhancement) paper.
3. That 5 (2) maximum marks be given for regularity in attending lectures and tutorials in each core and discipline specific elective (skill enhancement) paper. That the credit for regularity in each paper, based on attendance shall be as follows:

   The percentage of attendance in a paper

   I. More than 67% but less than 70% - 1 mark (0.4 mark)
   II. 70 or more but less than 75% - 2 marks (0.8 mark)
   III. 75 or more but less than 80% - 3 marks (1.2 marks)
   IV. 80 or more but less than 85% - 4 marks (1.6 marks)
   V. 85 and above - 5 marks (2 marks)

Semester wise Details of B.Sc. (Hons.) Mathematics Course & Credit Scheme

Sem-ester	Core Course(14)	Ability Enhancement Compulsory Course (AECC)(2)	Skill Enhancement Course (SEC)(2)	Discipline Specific Elective (DSE)(4)	Generic Elective (GE)(4)	Total Credits
I	BMATH101:Calculus (including practicals) BMATH102: Algebra	(English Communication/MIL)/ Environmental Science			GE-1	
L+T/P	4 + 2 = 6; 5 + 1 = 6	4			5+1 = 6	22
II	BMATH203: Real Analysis BMATH204: Differential Equations (including practicals)	(English Communication/MIL)/ Environmental Science			GE-2	
L+T/P	5 + 1 = 6; 4 + 2 = 6	4			5+1 = 6	22
III	BMATH305: Theory of Real Functions BMATH306: Group Theory-I BMATH307: Multivariate Calculus (including practicals)		SEC-1 LaTeX and HTML		GE-3	
L+T/P	5 + 1 = 6; 5 + 1 = 6; 4 + 2 = 6		4		5 +1 = 6	28
IV	BMATH408: Partial Differential Equations (including practicals) BMATH409: Riemann Integration and Series of Functions BMATH410: Ring Theory and Linear Algebra-I		SEC-2 Computer Algebra Systems and Related Software		GE-4	
L+T/P	4 + 2 = 6; 5 + 1 = 6; 5 + 1 = 6		4		5 +1 = 6	28
V	BMATH511: Metric Spaces BMATH512: Group Theory-II			DSE-1 (including practicals) DSE-2		
L+T/P	5 + 1 = 6; 5 + 1 = 6			4 + 2 = 6; 5 + 1 = 6		24

Sem-ester	**Core Course(14)**	**Ability Enhancement Compulsory Course (AECC)(2)**	**Skill Enhancement Course (SEC)(2)**	**Discipline Specific Elective (DSE)(4)**	**Generic Elective (GE)(4)**	**Total Credits**
VI	BMATH613: Complex Analysis (including practicals)			DSE-3		
	BMATH614: Ring Theory and Linear Algebra-II			DSE-4		
L+T/P	4 + 2 = 6; 5 + 1 = 6			5 + 1 = 6; 5 + 1 = 6		24

Total Credits = 148

Legend: L: Lecture Class; T: Tutorial Class; P: Practical Class
Note: One-hour lecture per week equals 1 Credit, 2 Hours practical class per week equals 1 credit. Practical in a group of 15-20 students in Computer Lab and Tutorial in a group of 8-12 students.

List of Discipline Specific Elective (DSE) Courses:

DSE-1 (including practicals): Any *one* of the following
(at least *two* shall be offered by the college)

(i). Numerical Analysis
(ii). Mathematical Modeling and Graph Theory
(iii). C++ Programming for Mathematics

DSE-2: Any *one* of the following (at least *two* shall be offered by the college)

(i). Probability Theory and Statistics
(ii). Discrete Mathematics
(iii). Cryptography and Network Security

DSE-3: Any *one* of the following (at least *two* shall be offered by the college)

(i). Mathematical Finance
(ii). Introduction to Information Theory and Coding
(iii). Biomathematics

DSE-4: Any *one* of the following (at least *two* shall be offered by the college)

(i). Number Theory
(ii). Linear Programming and Applications
(iii). Mechanics

IV: Course Wise Content Details for B.Sc. (Hons.) Mathematics Programme:

Semester-I

BMATH101: Calculus

Total Marks: 150 (Theory: 75, Internal Assessment: 25 and Practical: 50)
Workload: 4 Lectures, 4 Practicals (per week) **Credits:** 6 (4+2)
Duration: 14 Weeks (56 Hrs. Theory + 56 Hrs. Practical) **Examination:** 3 Hrs.

Course Objectives: The primary objective of this course is to introduce the basic tools of calculus and geometric properties of different conic sections which are helpful in understanding their applications in planetary motion, design of telescope and to the real-world problems. Also, to carry out the hand on sessions in computer lab to have a deep conceptual understanding of the above tools to widen the horizon of students' self-experience.

Course Learning Outcomes: This course will enable the students to:
i) Sketch curves in a plane using its mathematical properties in the different coordinate systems of reference.
ii) Apply derivatives in Optimization, Social sciences, Physics and Life sciences etc.
iii) Compute area of surfaces of revolution and the volume of solids by integrating over cross-sectional areas.

Course Contents:

Unit 1: Derivatives for Graphing and Applications (Lectures: 12)
The first-derivative test for relative extrema, Concavity and inflection points, Second-derivative test for relative extrema, Curve sketching using first and second derivative tests; Limits to infinity and infinite limits, Graphs with asymptotes, L'Hôpital's rule; Applications in Business, Economics and Life Sciences; Higher order derivatives, Leibniz rule.

Unit 2: Sketching and Tracing of Curves (Lectures: 16)
Parametric representation of curves and tracing of parametric curves (except lines in $\mathbb{R}^3$), Polar coordinates and tracing of curves in polar coordinates; Techniques of sketching conics, Reflection properties of conics, Rotation of axes and second degree equations, Classification into conics using the discriminant.

Unit 3: Volume and Area of Surfaces (Lectures: 16)
Volumes by slicing disks and method of washers, Volumes by cylindrical shells, Arc length, Arc length of parametric curves, Area of surface of revolution; Hyperbolic functions; Reduction formulae.

Unit 4: Vector Calculus and its Applications (Lectures: 12)
Introduction to vector functions and their graphs, Operations with vector functions, Limits and continuity of vector functions, Differentiation and integration of vector functions; Modeling ballistics and planetary motion, Kepler's second law; Unit tangent, Normal and binormal vectors, Curvature.

References:

1. Anton, Howard, Bivens, Irl, & Davis, Stephen (2013). *Calculus* (10th ed.). John Wiley & Sons Singapore Pte. Ltd. Indian Reprint (2016) by Wiley India Pvt. Ltd. Delhi.
2. Prasad, Gorakh (2016). *Differential Calculus* (19th ed.). Pothishala Pvt. Ltd. Allahabad.
3. Strauss, Monty J., Bradley, Gerald L., & Smith, Karl J. (2007). *Calculus* (3rd ed.). Dorling Kindersley (India) Pvt. Ltd. (Pearson Education). Delhi. Indian Reprint 2011.

Additional Reading:

i. Thomas, Jr. George B., Weir, Maurice D., & Hass, Joel (2014). *Thomas' Calculus* (13th ed.). Pearson Education, Delhi. Indian Reprint 2017.

Practical / Lab work to be performed in Computer Lab.

List of the practicals to be done using Mathematica /MATLAB /Maple /Scilab/Maxima etc.

(i). Plotting the graphs of the following functions: ax, $[x]$ (greatest integer function),
$\sqrt{ax+b}$, $|ax+b|$, $c\pm\ |ax+b|$, $x^{\pm n}$, $x^{1/n}$ $(n\in\mathbb{Z})$,
$|x|/x$, $\sin(1/x)$, $x\sin(1/x)$, and , $e^{\pm 1/x}$, for $x\neq 0$.
e^{ax+b}, $\log(ax+b)$, $1/(ax+b)$, $\sin(ax+b)$, $\cos(ax+b)$, $|\sin(ax+b)|$, $|\cos(ax+b)|$.
Observe and discuss the effect of changes in the real constants *a*, *b* and *c* on the graphs.

(ii). Plotting the graphs of polynomial of degree 4 and 5, and their first and second derivatives, and analysis of these graphs in context of the concepts covered in Unit 1.
(iii). Sketching parametric curves, e.g., Trochoid, Cycloid, Epicycloid and Hypocycloid.
(iv). Tracing of conic in Cartesian coordinates.
(v). Obtaining surface of revolution of curves.
(vi). Graph of hyperbolic functions.
(vii). Computation of limit, Differentiation, Integration and sketching of vector-valued functions.
(viii). Complex numbers and their representations, Operations like addition, Multiplication, Division, Modulus. Graphical representation of polar form.
(ix). Find numbers between two real numbers and plotting of finite and infinite subset of $\mathbb{R}$.
(x). **Matrix Operations:** Addition, Multiplication, Inverse, Transpose, Determinant, Rank, Eigenvectors, Eigenvalues, Characteristic equation and verification of the Cayley-Hamilton theorem, Solving the systems of linear equations.

Teaching Plan (Theory of BMATH101: Calculus):

Week 1: The first-derivative test for relative extrema, Concavity and inflection points, Second-derivative test for relative extrema, Curve sketching using first and second derivative tests.
[3] Chapter 4 (Section 4.3)

Week 2: Limits to infinity and infinite limits, Graphs with asymptotes, Vertical tangents and cusps, L'Hôpital's rule.
[3] Chapter 4 (Sections 4.4, and 4.5)

Week 3: Applications of derivatives in Business, Economics and Life sciences. Higher order derivatives and Leibniz rule for higher order derivatives for the product of two functions.
[3] Chapter 4 (Section 4.7)
[2] Chapter 5 (Sections 5.1, 5.2, and 5.4)

Week 4: Parametric representation of curves and tracing of parametric curves (except lines in $\mathbb{R}^3$), Polar coordinates and the relationship between Cartesian and polar coordinates.
[3] Chapter 9 [Section 9.4 (pages 471 to 475)]
[1] Chapter 10 (Sections 10.1, 10.2, up to Example 2, page 707)

Weeks 5 and 6: Tracing of curves in polar coordinates. Techniques of sketching conics**:** Parabola, Ellipse and Hyperbola.
[1] Chapter 10 [Sections 10.2 (pages 707 to 717), and 10.4 up to Example 10 page 742)]

Week 7: Reflection properties of conics, Rotation of axes, Second degree equations and their classification into conics using the discriminant.
[1] Chapter 10 [Sections 10.4 (pages 742 to 744), and 10.5]

Weeks 8 and 9: Volumes by slicing disks and method of washers, Volumes by cylindrical shells, Arc length, Arc length of parametric curves.
[1] Chapter 5 (Sections 5.2, 5.3, and 5.4)

Week 10: Area of surface of revolution; Hyperbolic functions.
[1] Chapter 5 (Section 5.5), and Chapter 6 (Section 6.8)

Week 11: Reduction formulae, and to obtain the iterative formulae for the integrals of the form**:** $\int \sin^n x\,dx,\ \int \cos^n x\,dx,\ \int \tan^n x\,dx, \int \sec^n x\,dx,$ and $\int \sin^m x \cos^n x\,dx.$
[1] Chapter 7 [Sections 7.2, and 7.3 (pages 497 to 503)]

Week 12: Introduction to vector functions and their graphs, Operations with vector functions, Limits and continuity of vector functions, Differentiation and tangent vectors.
[3] Chapter 10 (Sections 10.1, and 10.2 up to page 504)

Week 13: Properties of vector derivatives and integration of vector functions; Modeling ballistics and planetary motion, Kepler's second law.
[3] Chapter 10 (Sections 10.2 (pages 505 to 511), and 10.3)

Week 14: Unit tangent, Normal and binormal vectors, Curvature.
[1] Chapter 12 (Sections 12.4, and 12.5)

BMATH102: Algebra

Total Marks: 100 (Theory: 75, Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: The primary objective of this course is to introduce the basic tools of theory of equations, complex numbers, number theory and matrices to understand their linkage to the real-world problems. Perform matrix algebra with applications to Computer Graphics.

Course Learning Outcomes: This course will enable the students to:

i) Employ De Moivre's theorem in a number of applications to solve numerical problems.
ii) Apply Euclid's algorithm and backwards substitution to find greatest common divisor.
iii) Recognize consistent and inconsistent systems of linear equations by the row echelon form of the augmented matrix, using rank.
iv) Find eigenvalues and corresponding eigenvectors for a square matrix.

Course Contents:

Unit 1: Theory of Equations and Complex Numbers (Lectures: 20)
Elementary theorems on the roots of an equation, Polynomials, The remainder and factor theorem, Synthetic division, Factored form of a polynomial, The Fundamental theorem of algebra, Relations between the roots and the coefficients of polynomial equations, Imaginary roots occur in pairs, Integral and rational roots; Polar representation of complex numbers, The *n*th roots of unity, De Moivre's theorem for integer and rational indices and its applications.

Unit 2: Equivalence Relations and Functions (Lectures: 10)
Equivalence relations, Functions, Composition of functions, Invertibility and inverse of functions, One-to-one correspondence and the cardinality of a set.

Unit 3: Basic Number Theory (Lectures: 10)
The division algorithm, Divisibility and the Euclidean algorithm, The fundamental theorem of arithmetic, Modular arithmetic and basic properties of congruences; Principles of mathematical induction and well ordering principle.

Unit 4: Row Echelon Form of Matrices and Applications (Lectures: 30)
Systems of linear equations, Row reduction and echelon forms, Vector equations, The matrix equation $A\mathbf{x} = b$, Solution sets of linear systems, Linear independence, The rank of a matrix and applications; Introduction to linear transformations, The matrix of a linear transformation; Matrix operations, The inverse of a matrix, Characterizations of invertible matrices, Applications to Computer Graphics, Eigenvectors and eigenvalues, The characteristic equation and the Cayley-Hamilton theorem.

References:

1. Andreescu, Titu & Andrica Dorin. (2014). *Complex Numbers from A to...Z.* (2nd ed.). Birkhäuser.

2. Dickson, Leonard Eugene (2009). *First Course in The Theory of Equations*. The Project Gutenberg EBook (http://www.gutenberg.org/ebooks/29785)
3. Goodaire, Edgar G., & Parmenter, Michael M. (2005). *Discrete Mathematics with Graph Theory* (3rd ed.). Pearson Education Pvt. Ltd. Indian Reprint 2015.
4. Kolman, Bernard, & Hill, David R. (2001). *Introductory Linear Algebra with Applications* (7th ed.). Pearson Education, Delhi. First Indian Reprint 2003.
5. Lay, David C., Lay, Steven R., & McDonald, Judi J. (2016). *Linear Algebra and its Applications* (5th ed.). Pearson Education.

Additional Readings:

i. Andrilli, Stephen, & Hecker, David (2016). *Elementary Linear Algebr*a (5th ed.). Academic Press, Elsevier India Private Limited.
ii. Burton, David M. (2012). *Elementary Number Theory* (7th ed.). McGraw-Hill Education Pvt. Ltd. Indian Reprint.

Teaching Plan (BMATH102: Algebra):

Weeks 1 and 2: Elementary theorems on the roots of an equation, Polynomials, The remainder and factor theorem, Synthetic division, Factored form of a polynomial, The Fundamental theorem of algebra, Relations between the roots and the coefficients of polynomial equations, Imaginary roots occur in pairs, Integral and rational roots.
[2] Chapter II (Sections 12 to 16, 19 to 21, 24 and 27, Statement of the Fundamental theorem of algebra)

Weeks 3 and 4: Polar representation of complex numbers, The *n*th roots of unity, De Moivre's theorem for integer and rational indices and its applications.
[1] Chapter 2

Weeks 5 and 6. Equivalence relations, Functions, Composition of functions, Invertibility and inverse of functions, One-to-one correspondence and the cardinality of a set.
[3] Chapter 2 (Section 2.4), and Chapter 3

Weeks 7 and 8: The division algorithm, Divisibility and the Euclidean algorithm, The fundamental theorem of arithmetic (statement only), Modular arithmetic and basic properties of congruences. Principles of mathematical induction and well ordering principle.
[3] Chapter 4 [Sections 4.1 up to 4.1.6, 4.2 up to 4.2.11, 4.3 (4.3.7 to 4.3.9), and 4.4 up to 4.4.8)], and Chapter 5 (Sections 5.1.1 and 5.1.4)

Weeks 9 and 10: Systems of linear equations, Row reduction and echelon forms, Vector equations, The matrix equation $A\mathbf{x}$ = b, Solution sets of linear systems, Linear independence, The rank of a matrix and applications (Definition and examples).
[5] Chapter 1 (Sections 1.1 to 1.5)
[4] Chapter 6 [Section 6.6 (pages 287 to 291)]

Week 11: Introduction to linear transformations, The matrix of a linear transformation.
[5] Chapter 1 (Sections 1.7 to 1.9)

Weeks 12 and 13: Matrix operations, The inverse of a matrix, Characterizations of invertible matrices, Applications to Computer Graphics.
[5] Chapter 2 (Sections 2.1 to 2.3, and 2.7 up to Example 6, page 142)

Week 14: Eigenvectors and eigenvalues, The characteristic equation and the Cayley-Hamilton theorem.
[4] Chapter 5 (Sections 5.1 and 5.2, Supplementary exercises 5 and 7, page 328)

Semester-II

BMATH203: Real Analysis

Total Marks: 100 (Theory: 75, Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: The course will develop a deep and rigorous understanding of real line $\mathbb{R}$ and of defining terms to prove the results about convergence and divergence of sequences and series of real numbers. These concepts have vide range of applications in real life scenario.

Course Learning Outcomes: This course will enable the students to:

i) Understand many properties of the real line $\mathbb{R}$ and learn to define sequence in terms of functions from $\mathbb{N}$ to a subset of $\mathbb{R}$.
ii) Recognize bounded, convergent, divergent, Cauchy and monotonic sequences and to calculate their limit superior, limit inferior, and the limit of a bounded sequence.
iii) Apply the ratio, root, alternating series and limit comparison tests for convergence and absolute convergence of an infinite series of real numbers.

Course Contents:

Unit 1: Real Number System $\mathbb{R}$ (Lectures: 10)
Algebraic and order properties of $\mathbb{R}$, Absolute value of a real number; Bounded above and bounded below sets, Supremum and infimum of a nonempty subset of $\mathbb{R}$.

Unit 2: Properties of $\mathbb{R}$ (Lectures: 10)
The completeness property of $\mathbb{R}$, Archimedean property, Density of rational numbers in $\mathbb{R}$; Definition and types of intervals, Nested intervals property; Neighborhood of a point in $\mathbb{R}$, Open and closed sets in $\mathbb{R}$.

Unit 3: Sequences in $\mathbb{R}$ (Lectures: 25)
Convergent sequence, Limit of a sequence, Bounded sequence, Limit theorems, Monotone sequences, Monotone convergence theorem, Subsequences, Bolzano-Weierstrass theorem for sequences, Limit superior and limit inferior for bounded sequence, Cauchy sequence, Cauchy's convergence criterion.

Unit 4: Infinite Series (Lectures: 25)
Convergence and divergence of infinite series of real numbers, Necessary condition for convergence, Cauchy criterion for convergence; Tests for convergence of positive term series**:** Integral test, Basic comparison test, Limit comparison test, D'Alembert's ratio test, Cauchy's *n*th root test; Alternating series, Leibniz test, Absolute and conditional convergence.

References:

1. Bartle, Robert G., & Sherbert, Donald R. (2015). *Introduction to Real Analysis* (4th ed.). Wiley India Edition. New Delhi.

2. Bilodeau, Gerald G., Thie, Paul R., & Keough, G. E. (2010). *An Introduction to Analysis* (2nd ed.). Jones & Bartlett India Pvt. Ltd. Student Edition. Reprinted 2015.
3. Denlinger, Charles G. (2011). *Elements of Real Analysis*. Jones & Bartlett India Pvt. Ltd. Student Edition. Reprinted 2015.

Additional Readings:

i. Ross, Kenneth A. (2013). *Elementary Analysis*: *The Theory of Calculus* (2nd ed.). Undergraduate Texts in Mathematics, Springer. Indian Reprint.
ii. Thomson, Brian S., Bruckner, Andrew. M., & Bruckner, Judith B. (2001). *Elementary Real Analysis*. Prentice Hall.

Teaching Plan (Theory of BMATH203: Real Analysis):

Weeks 1 and 2: Algebraic and order properties of $\mathbb{R}$ **.** Absolute value of a real number; Bounded above and bounded below sets, Supremum and infimum of a nonempty subset of $\mathbb{R}$.
[1] Chapter 2 [Sections 2.1, 2.2 (2.2.1 to 2.2.6), and 2.3 (2.3.1 to 2.3.5)]

Weeks 3 and 4: The completeness property of $\mathbb{R}$, Archimedean property, Density of rational numbers in $\mathbb{R}$; Definition and types of intervals, Nested intervals property; Neighborhood of a point in $\mathbb{R}$, Open and closed sets in $\mathbb{R}$.
[1] Chapter 2 [Sections 2.3 (2.3.6), 2.4 (2.4.3 to 2.4.9), and 2.5 up to Theorem 2.5.3]
[1] Chapter 11 [Section 11.1 (11.1.1 to 11.1.3)]

Weeks 5 and 6: Sequences and their limits, Bounded sequence, Limit theorems.
[1] Chapter 3 (Sections 3.1 and 3.2)

Week 7: Monotone sequences, Monotone convergence theorem and applications.
[1] Chapter 3 (Section 3.3)

Week 8: Subsequences and statement of the Bolzano-Weierstrass theorem. Limit superior and limit inferior for bounded sequence of real numbers with illustrations only.
[1] Chapter 3 [Section 3.4 (3.4.1 to 3.4.12), except 3.4.4, 3.4.7, 3.4.9 and 3.4.11]

Week 9: Cauchy sequences of real numbers and Cauchy's convergence criterion.
[1] Chapter 3 [Section 3.5 (3.5.1 to 3.5.6)]

Week 10: Convergence and divergence of infinite series, Sequence of partial sums of infinite series, Necessary condition for convergence, Cauchy criterion for convergence of series.
[3] Chapter 8 (Section 8.1)

Weeks 11 and 12: Tests for convergence of positive term series**:** Integral test statement and convergence of p-series, Basic comparison test, Limit comparison test with applications, D'Alembert's ratio test and Cauchy's nth root test.
[3] Chapter 8 (Section 8.2 up to 8.2.19)

Weeks 13 and 14: Alternating series, Leibniz test, Absolute and conditional convergence.
[2] Chapter 6 (Section 6.2)

BMATH204: Differential Equations

Total Marks: 150 (Theory: 75, Internal Assessment: 25 and Practical: 50)
Workload: 4 Lectures, 4 Practicals (per week) **Credits:** 6 (4+2)
Duration: 14 Weeks (56 Hrs. Theory + 56 Hrs. Practical) **Examination:** 3 Hrs.

Course Objectives: The main objectives of this course are to introduce the students to the exciting world of Differential Equations, Mathematical Modeling and their applications.

Course Learning Outcomes: The course will enable the students to:

i) Formulate Differential Equations for various Mathematical models.
ii) Solve first order non-linear differential equation and linear differential equations of higher order using various techniques.
iii) Apply these techniques to solve and analyze various mathematical models.

Course Contents:

Unit 1: Differential Equations and Mathematical Modeling (Lectures: 12)
Differential equations and mathematical models, Order and degree of a differential equation, Exact differential equations and integrating factors of first order differential equations, Reducible second order differential equations, Application of first order differential equations to equations to acceleration-velocity model, Growth and decay model.

Unit 2: Population Growth Models (Lectures: 12)
Introduction to compartmental models, Lake pollution model (with case study of Lake Burley Griffin), Drug assimilation into the blood (case of a single cold pill, case of a course of cold pills, case study of alcohol in the bloodstream), Exponential growth of population, Limited growth of population, Limited growth with harvesting.

Unit 3: Second and Higher Order Differential Equations (Lectures: 20)
General solution of homogeneous equation of second order, Principle of superposition for a homogeneous equation; Wronskian, its properties and applications, Linear homogeneous and non-homogeneous equations of higher order with constant coefficients, Euler's equation, Method of undetermined coefficients, Method of variation of parameters, Applications of second order differential equations to mechanical vibrations.

Unit 4: Analysis of Mathematical Models (Lectures: 12)
Interacting population models, Epidemic model of influenza and its analysis, Predator-prey model and its analysis, Equilibrium points, Interpretation of the phase plane, Battle model and its analysis.

References:

1. Barnes, Belinda & Fulford, Glenn R. (2015). *Mathematical Modelling with Case Studies, Using* Maple *and* MATLAB (3rd ed.). CRC Press, Taylor & Francis Group.
2. Edwards, C. Henry, Penney, David E., & Calvis, David T. (2015). *Differential Equation and Boundary Value Problems*: *Computing and Modeling* (5th ed.). Pearson Education.
3. Ross, Shepley L. (2004). *Differential Equations* (3rd ed.). John Wiley & Sons. India

Additional Reading:

i. Ross, Clay C. (2004). *Differential Equations*: *An Introduction with Mathematica*® (2nd ed.). Springer.

Practical /Lab work to be performed in a Computer Lab:

Modeling of the following problems using Mathematica /MATLAB/Maple/Maxima/Scilab etc.

1. Plotting of second and third order respective solution family of differential equation.
2. Growth and decay model (exponential case only).
3. (a) Lake pollution model (with constant/seasonal flow and pollution concentration).
   (b) Case of single cold pill and a course of cold pills.
   (c) Limited growth of population (with and without harvesting).
4. (a) Predatory-prey model (basic Volterra model, with density dependence, effect of DDT, two prey one predator).
   (b) Epidemic model of influenza (basic epidemic model, contagious for life, disease with carriers).
   (c) Battle model (basic battle model, jungle warfare, long range weapons).
5. Plotting of recursive sequences, and study the convergence.
6. Find a value $m \in \mathbb{N}$ that will make the following inequality holds for all $n > m$:

$$(i)\quad \left|\sqrt[n]{0.5}-1\right| < 10^{-3},\ (ii)\ \left|\sqrt[n]{n}-1\right| < 10^{-3},$$
$$(iii)\ (0.9)^n < 10^{-3},\qquad (iv)\ 2^n/n! < 10^{-7}, \text{ etc.}$$

7. Verify the Bolzano-Weierstrass theorem through plotting of sequences and hence identify convergent subsequences from the plot.
8. Study the convergence/divergence of infinite series of real numbers by plotting their sequences of partial sum.
9. Cauchy's root test by plotting *n*th roots.
10. D'Alembert's ratio test by plotting the ratio of *n*th and (*n*+1)th term of the given series of positive terms.
11. For the following sequences $\langle a_n \rangle$, given $\varepsilon = 1/2^k$, $p = 10^j$, $k = 0,1,2,\ldots;\ j = 1,2,3,\ldots$

    Find $m \in \mathbb{N}$ such that $(i)\ \left|a_{m+p} - a_m\right| < \varepsilon,\ \ (ii)\ \left|a_{2m+p} - a_{2m}\right| < \varepsilon,$ where a_n is given as:

$$(a)\ \frac{n+1}{n},\quad (b)\ \frac{1}{n},\qquad (c)\ 1-\frac{1}{2}+\frac{1}{3}-\cdots+\frac{(-1)^{n-1}}{n}$$
$$(d)\ \frac{(-1)^n}{n},\quad (e)\ 2^{-n}n^2,\quad (f)\ 1+\frac{1}{2!}+\cdots+\frac{1}{n!}$$

12. For the following series $\sum a_n$, calculate $(i)\ \left|\frac{a_{n+1}}{a_n}\right|$, $(ii)\ |a_n|^{1/n}$, for $n=10^j$, $j=1,2,3,\ldots$,

and identify the convergent series, where a_n is given as:

$(a)\ \left(\frac{1}{n}\right)^{1/n}$, $(b)\ \frac{1}{n}$, $(c)\ \frac{1}{n^2}$, $(d)\ \left(1+\frac{1}{\sqrt{n}}\right)^{-n^{3/2}}$, $(e)\ \frac{n!}{n^n}$

$(f)\ \frac{n^3+5}{3^n+2}$, $(g)\ \frac{1}{n^2+n}$, $(h)\ \frac{1}{\sqrt{n+1}}$, $(i)\ \cos n$, $(j)\ \frac{1}{n\log n}$, $(k)\ \frac{1}{n(\log n)^2}$

Teaching Plan (Theory of BMATH204: Differential Equations):

Weeks 1 and 2: Differential equations and mathematical models, Order and degree of a differential equation, Exact differential equations and integrating factors of first order differential equations, Reducible second order differential equations.
[2] Chapter 1 (Sections 1.1, and 1.6)
[3] Chapter 2.

Week 3: Application of first order differential equations to equations to acceleration-velocity model, Growth and decay model.
[2] Chapter 1 (Section 1.4, pages 35 to 38), and Chapter 2 (Section 2.3)
[3] Chapter 3 (Section 3.3, A and B with Examples 3.8, 3.9)

Week 4: Introduction to compartmental models, Lake pollution model (with case study of Lake Burley Griffin).
[1] Chapter 2 (Sections 2.1, 2.5, and 2.6)

Week 5: Drug assimilation into the blood (case of a single cold pill, case of a course of cold pills, Case study of alcohol in the bloodstream).
[1] Chapter 2 (Sections 2.7, and 2.8)

Week 6: Exponential growth of population, Density dependent growth, Limited growth with harvesting.
[1] Chapter 3 (Sections 3.1 to 3.3)

Weeks 7 to 9: General solution of homogeneous equation of second order, Principle of superposition for a homogeneous equation; Wronskian, its properties and applications; Linear homogeneous and non-homogeneous equations of higher order with constant coefficients; Euler's equation.
[2] Chapter 3 (Sections 3.1 to 3.3)

Weeks 10 and 11: Method of undetermined coefficients, Method of variation of parameters; Applications of second order differential equations to mechanical vibrations.
[2] Chapter 3 (Sections 3.4 (pages 172 to 177), and 3.5)

Weeks 12 to 14: Interacting population models, Epidemic model of influenza and its analysis, Predator-prey model and its analysis, Equilibrium points, Interpretation of the phase plane, Battle model and its analysis.
[1] Chapter 5 (Sections 5.1, 5.2, 5.4, and 5.9), and Chapter 6 (Sections 6.1 to 6.4).

Semester-III

BMATH305: Theory of Real Functions

Total Marks: 100 (Theory: 75, Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: It is a basic course on the study of real valued functions that would develop an analytical ability to have a more matured perspective of the key concepts of calculus, namely, limits, continuity, differentiability and their applications.

Course Learning Outcomes: This course will enable the students to learn:

i) To have a rigorous understanding of the concept of limit of a function.
ii) The geometrical properties of continuous functions on closed and bounded intervals.
iii) The applications of mean value theorem and Taylor's theorem.

Course Contents:

Unit 1: Limits of Functions **(Lectures: 15)**
Limits of functions ($\varepsilon - \delta$ approach), Sequential criterion for limits, Divergence criteria, Limit theorems, One-sided limits, Infinite limits and limits at infinity.

Unit 2: Continuous Functions and their Properties **(Lectures: 25)**
Continuous functions, Sequential criterion for continuity and discontinuity, Algebra of continuous functions, Properties of continuous functions on closed and bounded intervals; Uniform continuity, Non-uniform continuity criteria, Uniform continuity theorem.

Unit 3: Derivability and its Applications **(Lectures: 20)**
Differentiability of a function, Algebra of differentiable functions, Carathéodory's theorem and chain rule; Relative extrema, Interior extremum theorem, Rolle's theorem, Mean- value theorem and its applications, Intermediate value property of derivatives - Darboux's theorem.

Unit 4: Taylor's Theorem and its Applications **(Lectures:10)**
Taylor polynomial, Taylor's theorem with Lagrange form of remainder, Application of Taylor's theorem in error estimation; Relative extrema, and to establish a criterion for convexity; Taylor's series expansions of e^x, $\sin x$ and $\cos x$.

Reference:

1. Bartle, Robert G., & Sherbert, Donald R. (2015). *Introduction to Real Analysis* (4th ed.). Wiley India Edition. New Delhi.

Additional Readings:

i. Ghorpade, Sudhir R. & Limaye, B. V. (2006). *A Course in Calculus and Real Analysis*. Undergraduate Texts in Mathematics, Springer (SIE). First Indian reprint.
ii. Mattuck, Arthur. (1999). *Introduction to Analysis*, Prentice Hall.
iii. Ross, Kenneth A. (2013). *Elementary Analysis*: *The Theory of Calculus* (2nd ed.). Undergraduate Texts in Mathematics, Springer. Indian Reprint.

Teaching Plan (Theory of BMATH305: Theory of Real Functions):

Week 1: Definition of the limit, Sequential criterion for limits, Criterion for non-existence of limit.
[1] Chapter 4 (Section 4.1)

Week 2: Algebra of limits of functions with illustrations and examples, Squeeze theorem.
[1] Chapter 4 (Section 4.2)

Week 3: Definition and illustration of the concepts of one-sided limits, Infinite limits and limits at infinity.
[1] Chapter 4 (Section 4.3)

Weeks 4 and 5: Definitions of continuity at a point and on a set, Sequential criterion for continuity, Algebra of continuous functions, Composition of continuous functions.
[1] Chapter 5 (Sections 5.1, and 5.2)

Weeks 6 and 7: Various properties of continuous functions defined on an interval, viz., Boundedness theorem, Maximum-minimum theorem, Statement of the location of roots theorem, Intermediate value theorem and the preservation of intervals theorem.
[1] Chapter 5 (Section 5.3)

Week 8: Definition of uniform continuity, Illustration of non-uniform continuity criteria, Uniform continuity theorem.
[1] Chapter 5 [Section 5.4 (5.4.1 to 5.4.3)]

Weeks 9 and 10: Differentiability of a function, Algebra of differentiable functions, Carathéodory's theorem and chain rule.
[1] Chapter 6 [Section 6.1 (6.1.1 to 6.1.7)]

Weeks 11 and 12: Relative extrema, Interior extremum theorem, Mean value theorem and its applications, Intermediate value property of derivatives- Darboux's theorem.
[1] Chapter 6 (Section 6.2)

Weeks 13 and 14: Taylor polynomial, Taylor's theorem and its applications, Taylor's series expansions of e^x, $\sin x$ and $\cos x$.
[1] Chapter 6 (Sections 6.4.1 to 6.4.6), and Chapter 9 (Example 9.4.14, page 286)

BMATH306: Group Theory-I

Total Marks: 100 (Theory: 75, Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: The objective of the course is to introduce the fundamental theory of groups and their homomorphisms. Symmetric groups and group of symmetries are also studied in detail. Fermat's Little theorem as a consequence of the Lagrange's theorem on finite groups.

Course Learning Outcomes: The course will enable the students to:

i) Recognize the mathematical objects that are groups, and classify them as abelian, cyclic and permutation groups, etc;
ii) Link the fundamental concepts of Groups and symmetrical figures;
iii) Analyze the subgroups of cyclic groups;
iv) Explain the significance of the notion of cosets, normal subgroups, and factor groups.

Course Contents:

Unit 1: Groups and its Elementary Properties (Lectures: 10)
Symmetries of a square, The Dihedral groups, Definition and examples of groups including permutation groups and quaternion groups (illustration through matrices), Elementary properties of groups.

Unit 2: Subgroups and Cyclic Groups (Lectures: 15)
Subgroups and examples of subgroups, Centralizer, Normalizer, Center of a group, Product of two subgroups; Properties of cyclic groups, Classification of subgroups of cyclic groups.

Unit 3: Permutation Groups and Lagrange's Theorem (Lectures: 25)
Cycle notation for permutations, Properties of permutations, Even and odd permutations, alternating groups; Properties of cosets, Lagrange's theorem and consequences including Fermat's Little theorem; Normal subgroups, factor groups, Cauchy's theorem for finite abelian groups.

Unit 4: Group Homomorphisms (Lectures: 20)
Group homomorphisms, Properties of homomorphisms, Group isomorphisms, Cayley's theorem, Properties of isomorphisms, First, Second and Third isomorphism theorems for groups.

Reference:

1. Gallian, Joseph. A. (2013). *Contemporary Abstract Algebra* (8th ed.). Cengage Learning India Private Limited, Delhi. Fourth impression, 2015.

Additional Reading:

i. Rotman, Joseph J. (1995). *An Introduction to The Theory of Groups* (4th ed.). Springer Verlag, New York.

Teaching Plan (BMATH306: Group Theory-I):

Week 1: Symmetries of a square, The Dihedral groups, Definition and examples of groups including permutation groups and quaternion groups (illustration through matrices)
[1] Chapter 1

Week 2: Definition and examples of groups, Elementary properties of groups.
[1] Chapter 2

Week 3: Subgroups and examples of subgroups, Centralizer, Normalizer, Center of a Group, Product of two subgroups.
[1] Chapter 3

Weeks 4 and 5: Properties of cyclic groups. Classification of subgroups of cyclic groups.
[1] Chapter 4

Weeks 6 and 7: Cycle notation for permutations, Properties of permutations, Even and odd permutations, Alternating group.
[1] Chapter 5 (up to page 110)

Weeks 8 and 9: Properties of cosets, Lagrange's theorem and consequences including Fermat's Little theorem.
[1] Chapter 7 (up to Example 6, page 150)

Week 10: Normal subgroups, Factor groups, Cauchy's theorem for finite abelian groups.
[1] Chapters 9 (Theorem 9.1, 9.2, 9.3 and 9.5, and Examples 1 to 12)

Weeks 11 and 12: Group homomorphisms, Properties of homomorphisms, Group isomorphisms, Cayley's theorem.
[1] Chapter 10 (Theorems 10.1 and 10.2, Examples 1 to 11)
[1] Chapter 6 (Theorem 6.1, and Examples 1 to 8)

Weeks 13 and 14: Properties of isomorphisms, First, Second and Third isomorphism theorems.
[1] Chapter 6 (Theorems 6.2 and 6.3, and Examples 1 to 8)
[1] Chapter 10 (Theorems 10.3, 10.4, Examples 12 to 14, and Exercises 41 and 42 for second and third isomorphism theorems for groups)

BMATH307: Multivariate Calculus

Total Marks: 150 (Theory: 75, Internal Assessment: 25 and Practical: 50)
Workload: 4 Lectures, 4 Practicals (per week) **Credits:** 6 (4+2)
Duration: 14 Weeks (56 Hrs. Theory + 56 Hrs. Practical) **Examination:** 3 Hrs.

Course Objectives: To understand the extension of the studies of single variable differential and integral calculus to functions of two or more independent variables. Also, the emphasis will be on the use of Computer Algebra Systems by which these concepts may be analyzed and visualized to have a better understanding.

Course Learning Outcomes: This course will enable the students to learn:

i) The conceptual variations when advancing in calculus from one variable to multivariable discussions.
ii) Inter-relationship amongst the line integral, double and triple integral formulations.
iii) Applications of multi variable calculus tools in physics, economics, optimization, and understanding the architecture of curves and surfaces in plane and space etc.

Course Contents:

Unit 1: Calculus of Functions of Several Variables (Lectures: 20)
Functions of several variables, Level curves and surfaces, Limits and continuity, Partial differentiation, Higher order partial derivative, Tangent planes, Total differential and differentiability, Chain rule, Directional derivatives, The gradient, Maximal and normal property of the gradient, Tangent planes and normal lines.

Unit 2: Extrema of Functions of Two Variables and Properties of Vector Field (Lectures: 8)
Extrema of functions of two variables, Method of Lagrange multipliers, Constrained optimization problems; Definition of vector field, Divergence and curl.

Unit 3: Double and Triple Integrals (Lectures: 16)
Double integration over rectangular and nonrectangular regions, Double integrals in polar co-ordinates, Triple integral over a parallelepiped and solid regions, Volume by triple integrals, triple integration in cylindrical and spherical coordinates, Change of variables in double and triple integrals.

Unit 4: Green's, Stokes' and Gauss Divergence Theorem (Lectures: 12)
Line integrals, Applications of line integrals**:** Mass and Work, Fundamental theorem for line integrals, Conservative vector fields, Green's theorem, Area as a line integral; Surface integrals, Stokes' theorem, The Gauss divergence theorem.

Reference:

1. Strauss, Monty J., Bradley, Gerald L., & Smith, Karl J. (2007). *Calculus* (3rd ed.). Dorling Kindersley (India) Pvt. Ltd. (Pearson Education). Delhi. Indian Reprint 2011.

Additional Reading:

i. Marsden, J. E., Tromba, A., & Weinstein, A. (2004). *Basic Multivariable Calculus*. Springer (SIE). First Indian Reprint.

Practical/Lab work to be performed in Computer Lab.

List of practicals similar to be done using Mathematica / MATLAB / Maple/Maxima/Scilab, etc.

1. Let $f(x)$ be any function and L be any real number. For given a and $\varepsilon > 0$, find a $\delta > 0$ such that for all x satisfying $0 < |x - a| < \delta$, the inequality $0 < |f(x) - l| < \varepsilon$ holds. For example:

   (a) $f(x) = x+1, L = 5, a = 4, \varepsilon = 0.01$

   (b) $f(x) = \sqrt{x+1}, L = 1, a = 4, \varepsilon = 0.1$

   (c) $f(x) = x^2, L = 4, a = -2, \varepsilon = 0.5$

   (d) $f(x) = \frac{1}{x}, L = -1, a = -1, \varepsilon = 0.1$

2. Discuss the limit of the following functions when x tends to 0:
   $\pm\frac{1}{x},\ \sin\left(\frac{1}{x}\right),\ \cos\left(\frac{1}{x}\right),\ x\sin\left(\frac{1}{x}\right),\ x\cos\left(\frac{1}{x}\right),\ x^2\sin\left(\frac{1}{x}\right),$
   $\frac{1}{x^n} (n \in \mathbb{N}),\ [x]$ greatest integer function, $\frac{1}{x}\sin(x)$.

3. Discuss the limit of the following functions when x tends to infinity:
   $e^{\pm\frac{1}{x}},\ \sin\left(\frac{1}{x}\right),\ \frac{1}{x}e^{\pm x},\ \frac{x}{x+1},\ x^2\sin\left(\frac{1}{x}\right),\ \frac{ax+b}{cx^2+dx+e}(a \neq 0 \neq c)$

4. Discuss the continuity of the functions at $x = 0$ in the Practical 2.

5. Illustrate the geometric meaning of Rolle's theorem of the following functions on the given interval: (i) $x^3 - 4x$ on [-2, 2]; (ii) $(x-3)^4(x-5)^3$ on [3, 5] etc.

6. Illustrate the geometric meaning of Lagrange's mean value theorem of the following functions on the given interval:
   (i) $\log x$ on [1/2, 2]; (ii) $x(x-1)(x-2)$ on [0, 1/2]; (iii) $2x^2 - 7x + 10$ on [2, 5] etc.

7. Draw the following surfaces and find level curves at the given heights:

   (a) $f(x, y) = 10 - x^2 - y^2;\ z = 1,\ z = 6,\ z = 9$
   (b) $f(x, y) = x^2 + y^2;\ z = 1,\ z = 6,\ z = 9$
   (c) $f(x, y) = x^3 - y;\ z = 1,\ z = 6$
   (d) $f(x, y) = x^2 + \frac{y^2}{4};\ z = 1,\ z = 5,\ z = 8$
   (e) $f(x, y) = 4x^2 + y^2;\ z = 0,\ z = 1,\ z = 6,\ z = 9$

8. Draw the following surfaces and discuss whether limit exits or not as (x, y) approaches to the given points. Find the limit, if it exists:

   (i) $f(x,y)=\dfrac{x+y}{x-y}$; $(x,y)\to(0,0)$ and $(x,y)\to(1,3)$

   (ii) $f(x,y)=\dfrac{x-y}{\sqrt{x^2+y^2}}$; $(x,y)\to(0,0)$ and $(x,y)\to(2,1)$

   (iii) $f(x,y)=(x+y)e^{xy}$; $(x,y)\to(1,1)$ and $(x,y)\to(1,0)$

   (iv) $f(x,y)=e^{xy}$; $(x,y)\to(0,0)$ and $(x,y)\to(1,0)$

   (v) $f(x,y)=\dfrac{x+y^2}{x^2+y^2}$; $(x,y)\to(0,0)$

   (vi) $f(x,y)=\dfrac{x^2-y^2}{x^2+y^2}$; $(x,y)\to(0,0)$ and $(x,y)\to(2,1)$

9. Draw the tangent plane to the following surfaces at the given point:

   (i) $f(x,y)=\sqrt{x^2+y^2}$ at $(3,1,\sqrt{10})$

   (ii) $f(x,y)=10-x^2-y^2$ at $(2,2,2)$

   (iii) $x^2+y^2+z^2=9$ at $(3,0,0)$

   (iv) $z=\tan^{-1}x$ at $(1,\sqrt{3},\ \pi/3)$ and $(2,\ 2,\ \pi/4)$

   (v) $z=\log|x+y^2|$ at $(-3,-2,0)$

10. Use an incremental approximation to estimate the following functions at the given point and compare it with calculated value:

    (i) $f(x,y)=3x^4+2y^4$ at $(1.01,2.03)$

    (ii) $f(x,y)=x^5-2y^3$ at $(0.98,1.03)$

    (iii) $f(x,y)=e^{xy}$ at $(1.01,0.98)$

11. Find critical points and identify relative maxima, relative minima or saddle points to the following surfaces, if it exists:
    (i) $z=x^2+y^2$; (ii) $z=1-x^2-y^2$; (iii) $z=y^2-x^2$; (iv) $z=x^2y^4$.

12. Draw the following regions D and check whether these regions are of **Type I** or **Type II**:

    (i) $D=\{(x,y):0\le x\le 2, 1\le y\le e^x\}$

    (ii) $D=\{(x,y):\log y\le x\le 2, 1\le y\le e^2\}$

    (iii) $D=\{(x,y):0\le x\le 1, x^3\le y\le 1\}$

    (iv) The region D is bounded by $y=x^2-2$ and the line $y = x$.

    (v) $D=\{(x,y):0\le x\le \dfrac{\pi}{4}, \sin x\le y\le \cos x\}$

Teaching Plan (Theory of BMATH307: Multivariate Calculus):

Week 1: Definition of functions of several variables, Graphs of functions of two variables – Level curves and surfaces, Limits and continuity of functions of two variables.
[1] Chapter 11 (Sections 11.1 and 11.2)

Week 2: Partial differentiation, and partial derivative as slope and rate, Higher order partial derivatives. Tangent planes, incremental approximation, Total differential.
[1] Chapter 11 (Sections 11.3 and 11.4)

Week 3: Differentiability, Chain rule for one parameter, Two and three independent parameters.
[1] Chapter 11 (Sections 11.4 and 11.5)

Week 4: Directional derivatives, The gradient, Maximal and normal property of the gradient, Tangent planes and normal lines.
[1] Chapter 11 (Section 11.6)

Week 5: First and second partial derivative tests for relative extrema of functions of two variables, and absolute extrema of continuous functions.
[1] Chapter 11 [Section 11.7 (up to page 605)]

Week 6: Lagrange multipliers method for optimization problems with one constraint, Definition of vector field, Divergence and curl.
[1] Chapter 11 [Section 11.8 (pages 610-614)], Chapter13 (Section 13.1)

Week 7: Double integration over rectangular and nonrectangular regions.
[1] Chapter 12 (Sections 12.1 and 12.2)

Week 8: Double integrals in polar co-ordinates, and triple integral over a parallelepiped.
[1] Chapter 12 (Sections 12.3 and 12.4)

Week 9: Triple integral over solid regions, Volume by triple integrals, and triple integration in cylindrical coordinates.
[1] Chapter 12 (Sections 12.4 and 12.5)

Week 10: Triple integration in spherical coordinates, Change of variables in double and triple integrals.
[1] Chapter 12 (Sections 12.5 and 12.6)

Week 11: Line integrals and its properties, applications of line integrals: mass and work.
[1] Chapter 13 (Section 13.2)

Week 12: Fundamental theorem for line integrals, Conservative vector fields and path independence.
[1] Chapter 13 (Section 13.3)

Week 13: Green's theorem for simply connected region, Area as a line integral, Definition of surface integrals
[1] Chapter 13 [Sections 13.4 (pages 712 to 716), 13.5 (pages 723 to 726)]

Week 14: Stokes' theorem and the divergence theorem.
[1] Chapter 13 [Sections 13.6 (pages 733 to 737), 13.7 (pages 742 to 745)]

Note. To improve the problem solving ability, for similar kind of examples based upon the above contents, the additional reading [i] may be consulted.

Skill Enhancement Paper

SEC-1: LaTeX and HTML

Total Marks: 100 (Theory: 38, Internal Assessment: 12, and Practical: 50)
Workload: 2 Lectures, 4 Practicals (per week) **Credits:** 4 (2+2)
Duration: 14 Weeks (28 Hrs. Theory + 56 Hrs. Practical) **Examination:** 2 Hrs.

Course Objectives: The purpose of this course is to acquaint students with the latest typesetting skills, which shall enable them to prepare high quality typesetting, beamer presentation and webpages.

Course Learning Outcomes: After studying this course the student will be able to:
i) Typeset mathematical formulas, use nested list, tabular & array environments.
ii) Create or import graphics.
iii) Use beamer to create presentation and HTML to create a web page.

Course Contents:

Unit 1: Getting Started with LaTeX **(Lectures: 6)**
Introduction to TeX and LaTeX, Typesetting a simple document, Adding basic information to a document, Environments, Footnotes, Sectioning and displayed material.

Unit 2: Mathematical Typesetting with LaTeX **(Lectures: 6)**
Accents and symbols, Mathematical Typesetting (Elementary and Advanced)**:** Subscript/ Superscript, Fractions, Roots, Ellipsis, Mathematical Symbols, Arrays, Delimiters, Multiline formulas, Spacing and changing style in math mode.

Unit 3: Graphics and Beamer Presentation in LaTeX **(Lectures: 8)**
Graphics in LaTeX, Simple pictures using PS Tricks, Plotting of functions, Beamer presentation.

Unit 4: HTML **(Lectures: 8)**
HTML basics, Creating simple web pages, Images and links, Design of web pages.

References:

1. Bindner, Donald & Erickson, Martin. (2011). *A Student's Guide to the Study, Practice, and Tools of Modern Mathematics*. CRC Press, Taylor & Francis Group, LLC.
2. Lamport, Leslie (1994). *LaTeX*: *A Document Preparation System*, User's Guide and Reference Manual (2nd ed.). Pearson Education. Indian Reprint.

Additional Readings:

i. Dongen, M. R. C. van (2012). *LaTeX and Friends*. Springer-Verlag.
ii. Robbins, J. N. (2018). *Learning Web Design*: *A Beginner's Guide to HTML* (5th ed.). O'Reilly Media Inc.

Practical/Lab work to be performed in Computer Lab.

Practicals:

[1] Chapter 9 (Exercises 4 to 10), Chapter 10 (Exercises 1 to 4 and 6 to 9), Chapter 11 (Exercises 1, 3, 4, and 5), and Chapter 15 (Exercises 5, 6 and 8 to 11).

Teaching Plan (Theory of SEC-1: LaTeX and HTML):

Weeks 1 to 3: Introduction to TeX and LaTeX, Typesetting a simple document, Adding basic information to a document, Environments, Footnotes, Sectioning and displayed material.
[1] Chapter 9 (9.1 to 9.5)
[2] Chapter 2 (2.1 to 2.5)

Weeks 4 to 6: Accents of symbols, Mathematical typesetting (elementary and advanced): subscript/superscript, Fractions, Roots, Ellipsis, Mathematical symbols, Arrays, Delimiters, Multiline formulas, Spacing and changing style in math mode.
[1] Chapter 9 (9.6 and 9.7)
[2] Chapter 3 (3.1 to 3.3)

Weeks 7 and 8: Graphics in LaTeX, Simple pictures using PS Tricks, Plotting of functions.
[1] Chapter 9 (Section 9.8)
[1] Chapter 10 (10.1 to 10.3)
[2] Chapter 7 (7.1 and 7.2)

Weeks 9 and 10: Beamer presentation.
[1] Chapter 11 (Sections 11.1 to 11.4)

Weeks 11 and 12: HTML basics, Creating simple web pages.
[1] Chapter 15 (Sections 15.1 and 15.2)

Weeks 13 and 14: Adding images and links, Design of web pages.
[1] Chapter 15 (Sections 15.3 to 15.5)

Semester-IV

BMATH408: Partial Differential Equations

Total Marks: 150 (Theory: 75, Internal Assessment: 25 and Practical: 50)
Workload: 4 Lectures, 4 Practicals (per week) **Credits:** 6 (4+2)
Duration: 14 Weeks (56 Hrs. Theory + 56 Hrs. Practical) **Examination:** 3 Hrs.

Course Objectives: The main objectives of this course are to teach students to form and solve partial differential equations and use them in solving some physical problems.

Course Learning Outcomes: The course will enable the students to:

i) Formulate, classify and transform partial differential equations into canonical form.
ii) Solve linear and non-linear partial differential equations using various methods; and apply these methods in solving some physical problems.

Course Contents:

Unit 1: First Order PDE and Method of Characteristics (Lectures: 12)
Introduction, Classification, Construction and geometrical interpretation of first order partial differential equations (PDE), Method of characteristic and general solution of first order PDE, Canonical form of first order PDE, Method of separation of variables for first order PDE.

Unit 2: Mathematical Models and Classification of 2nd Order Linear PDE (Lectures: 12)
Gravitational potential, Conservation laws and Burger's equations, Classification of second order PDE, Reduction to canonical forms, Equations with constant coefficients, General solution.

Unit 3: The Cauchy Problem and Wave Equations (Lectures: 16)
Mathematical modeling of vibrating string, vibrating membrane. Cauchy problem for second order PDE, Homogeneous wave equation, Initial boundary value problems, Non-homogeneous boundary conditions, Finite strings with fixed ends, Non-homogeneous wave equation, Goursat problem.

Unit 4: Method of Separation of Variables (Lectures: 16)
Method of separation of variables for second order PDE, Vibrating string problem, Existence and uniqueness of solution of vibrating string problem, Heat conduction problem, Existence and uniqueness of solution of heat conduction problem, Non-homogeneous problem.

Reference:

1. Myint-U, Tyn & Debnath, Lokenath. (2007). *Linear Partial Differential Equation for Scientists and Engineers* (4th ed.). Springer, Third Indian Reprint, 2013.

Additional Readings:

i. Sneddon, I. N. (2006). *Elements of Partial Differential Equations*, Dover Publications. Indian Reprint.
ii. Stavroulakis, Ioannis P & Tersian, Stepan A. (2004). *Partial Differential Equations*: *An Introduction with Mathematica and* MAPLE (2nd ed.). World Scientific.

Practical /Lab work to be performed in a Computer Lab:

Modeling of the following similar problems using Mathematica /MATLAB/ Maple/ Maxima/ Scilab etc.

1. Solution of Cauchy problem for first order PDE.
2. Plotting the characteristics for the first order PDE.
3. Plot the integral surfaces of a given first order PDE with initial data.
4. Solution of wave equation $\frac{\partial^2 u}{\partial t^2} = c^2 \frac{\partial^2 u}{\partial x^2}$ for any two of the following associated conditions:

(a) $u(x,0) = \phi(x), \quad u(x,0) = \psi(x), \; x \in \mathbb{R}, \; t > 0$
(b) $u(x,0) = \phi(x), \; u_t(x,0) = \psi(x), \quad u(0,t) = 0, x > 0 \;\; t > 0$
(c) $u(x,0) = \phi(x), \; u_t(x,0) = \psi(x), \; u_x(0,t) = 0, \;\; x > 0, \; t > 0$
(d) $u(x,0) = \phi(x), \quad u(x,0) = \psi(x), \quad u(0,t) = 0, \; u(l,t) = 0, 0 < x < l, \;\; t > 0$

5. Solution of one-Dimensional heat equation $u_t = k\, u_{xx}$, for a homogeneous rod of length l.
   That is - solve the IBVP:

$$u_t = k\, u_{xx}, \qquad 0 < x < l, \qquad t > 0$$
$$u(0,t) = 0, \qquad u(l,t) = 0, \qquad t \geq 0$$
$$u(0,t) = f(x), \;\; 0 \leq x \leq l$$

6. Solving systems of ordinary differential equations.

7. Draw the following sequence of functions on the given interval and discuss the pointwise convergence:

(i) $f_n(x) = x^n$ for $x \in \mathbb{R}$,
(ii) $f_n(x) = \frac{x}{n}$ for $x \in \mathbb{R}$,
(iii) $f_n(x) = \frac{x^2+nx}{n}$ for $x \in \mathbb{R}$,
(iv) $f_n(x) = \frac{\sin nx + n}{n}$ for $x \in \mathbb{R}$
(v) $f_n(x) = \frac{x}{x+n}$ for $x \in \mathbb{R}$ $x \geq 0$,
(vi) $f_n(x) = \frac{nx}{1+n^2x^2}$ for $x \in \mathbb{R}$
(vii) $f_n(x) = \frac{nx}{1+nx}$ for $x \in \mathbb{R}, x \geq 0$,
(viii) $f_n(x) = \frac{x^n}{1+x^n}$ for $x \in \mathbb{R}, x \geq 0$

8. Discuss the uniform convergence of sequence of functions (i) to (viii) given above in (7).

Teaching Plan (Theory of BMATH408: Partial Differential Equations):

Week 1: Introduction, Classification, Construction of first order partial differential equations (PDE).
[1] Chapter 2 (Sections 2.1 to 2.3)

Week 2: Method of characteristics and general solution of first order PDE.
[1] Chapter 2 (Sections 2.4 and 2.5)

Week 3: Canonical form of first order PDE, Method of separation of variables for first order PDE.

[1] Chapter 2 (Sections 2.6 and 2.7)

Week 4: The vibrating string, Vibrating membrane, Gravitational potential, Conservation laws.
[1] Chapter 3 (Sections 3.1 to 3.3, 3.5, and 3.6)

Weeks 5 and 6: Reduction to canonical forms, Equations with constant coefficients, General solution.
[1] Chapter 4 (Sections 4.1 to 4.5)

Weeks 7 and 8: The Cauchy problem for second order PDE, Homogeneous wave equation.
[1] Chapter 5 (Sections 5.1, 5.3, and 5.4)

Weeks 9 and 10: Initial boundary value problem, Non-homogeneous boundary conditions, Finite string with fixed ends, Non – homogeneous wave equation, Goursat problem.
[1] Chapter 5 (Sections 5.5 to 5.7, and 5.9)

Weeks 11 and 12: Method of separation of variables for second order PDE, Vibrating string problem.
[1] Chapter 7 (Sections 7.1 to 7.3)

Weeks 13 and 14: Existence (omit proof) and uniqueness of vibrating string problem. Heat conduction problem. Existence (omit proof) and uniqueness of the solution of heat conduction problem. Non – homogeneous problem.
[1] Chapter 7 (Sections 7.4 to 7.6, and 7.8)

BMATH409: Riemann Integration & Series of Functions

Total Marks: 100 (Theory: 75 and Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: To understand the integration of bounded functions on a closed and bounded interval and its extension to the cases where either the interval of integration is infinite, or the integrand has infinite limits at a finite number of points on the interval of integration. The sequence and series of real valued functions, and an important class of series of functions (i.e., power series).

Course Learning Outcomes: The course will enable the students to learn about:

i) Some of the families and properties of Riemann integrable functions, and the applications of the fundamental theorems of integration.
ii) Beta and Gamma functions and their properties.
iii) The valid situations for the inter-changeability of differentiability and integrability with infinite sum, and approximation of transcendental functions in terms of power series.

Course Contents:

Unit 1: Riemann Integration (Lectures: 25)
Definition of Riemann integration, Inequalities for upper and lower Darboux sums, Necessary and sufficient conditions for the Riemann integrability, Definition of Riemann integration by Riemann sum and equivalence of the two definitions, Riemann integrability of monotone functions and continuous functions, Properties of Riemann integrable functions, Definitions of piecewise continuous and piecewise monotone functions and their Riemann integrability, intermediate value theorem for integrals, Fundamental theorems (I and II) of calculus, and the integration by parts.

Unit 2: Improper Integral (Lectures: 10)
Improper integrals of Type-I, Type-II and mixed type, Convergence of Beta and Gamma functions, and their properties.

Unit 3: Sequence and Series of Functions (Lectures: 25)
Pointwise and uniform convergence of sequence of functions, Theorem on the continuity of the limit function of a sequence of functions, Theorems on the interchange of the limit and derivative, and the interchange of the limit and integrability of a sequence of functions. Pointwise and uniform convergence of series of functions, Theorems on the continuity, Derivability and integrability of the sum function of a series of functions, Cauchy criterion and the Weierstrass M-Test for uniform convergence.

Unit 4: Power Series (Lectures: 10)
Definition of a power series, Radius of convergence, Absolute convergence (Cauchy-Hadamard theorem), Uniform convergence, Differentiation and integration of power series, Abel's Theorem.

References:

1. Bartle, Robert G., & Sherbert, Donald R. (2015). *Introduction to Real Analysis* (4th ed.). Wiley India Edition. Delhi.
2. Denlinger, Charles G. (2011). *Elements of Real Analysis*. Jones & Bartlett (Student Edition). First Indian Edition. Reprinted 2015.
3. Ghorpade, Sudhir R. & Limaye, B. V. (2006). *A Course in Calculus and Real Analysis*. Undergraduate Texts in Mathematics, Springer (SIE). First Indian reprint.
4. Ross, Kenneth A. (2013). *Elementary Analysis*: *The Theory of Calculus* (2nd ed.). Undergraduate Texts in Mathematics, Springer.

Additional Reading:

i. Bilodeau, Gerald G., Thie, Paul R., & Keough, G. E. (2010). *An Introduction to Analysis* (2nd ed.). Jones & Bartlett India Pvt. Ltd. Student Edition. Reprinted 2015.

Teaching Plan (BMATH409: Riemann Integration & Series of Functions):

Week 1: Definition of Riemann integration, Inequalities for upper and lower Darboux sums.
[4] Chapter 6 [Section 32 (32.1 to 32.4)]

Week 2: Necessary and sufficient conditions for the Riemann integrability, Definition of Riemann integration by Riemann sum and equivalence of the two definitions.
[4] Chapter 6 [Section 32 (32.5 to 32.10)]

Week 3: Riemann integrability of monotone functions and continuous functions, Algebra and properties of Riemann integrable functions.
[4] Chapter 6 [Section 33 (33.1 to 33.6)]

Week 4: Definitions of piecewise continuous and piecewise monotone functions and their Riemann integrability, Intermediate value theorem for integrals.
[4] Chapter 6 [Section 33 (33.7 to 33.10)]

Week 5: First and second fundamental theorems of integral calculus, and the integration by parts.
[4] Chapter 6 [Section 34 (34.1 to 34.3)]

Week 6: Improper integrals of Type-I, Type-II and mixed type.
[2] Chapter 7 [Section 7.8 (7.8.1 to 7.8.18)]

Week 7: Convergence of Beta and Gamma functions, and their properties.
[3] Pages 405 - 408

Week 8: Definitions and examples of pointwise and uniformly convergent sequence of functions.
[1] Chapter 8 [Section 8.1 (8.1.1 to 8.1.10)]

Week 9: Motivation for uniform convergence by giving examples. Theorem on the continuity of the limit function of a sequence of functions.
[1] Chapter 8 [Section 8.2 (8.2.1 to 8.2.2)]

Week 10: The statement of the theorem on the interchange of the limit function and derivative, and its illustration with the help of examples. The interchange of the limit function and integrability of a sequence of functions.
[1] Chapter 8 [Section 8.2 (Theorems 8.2.3, and 8.2.4)]

Week 11: Pointwise and uniform convergence of series of functions, Theorems on the continuity, derivability and integrability of the sum function of a series of functions.
[1] Chapter 9 [Section 9.4 (9.4.1 to 9.4.4)]
Week 12: Cauchy criterion for the uniform convergence of series of functions, and the Weierstrass M-Test for uniform convergence.
[2] Chapter 9 [Section 9.4 (9.4.5 to 9.4.6)]

Week 13: Definition of a power series, Radius of convergence, Absolute and uniform convergence of a power series.
[4] Chapter 4 (Section 23)

Week 14: Differentiation and integration of power series, Statement of Abel's Theorem and its illustration with the help of examples.
[4] Chapter 4 [Section 26 (26.1 to 26.6)]

BMATH410: Ring Theory & Linear Algebra-I

Total Marks: 100 (Theory: 75 and Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: The objective of this course is to introduce the fundamental theory of two objects, namely - rings and vector spaces, and their corresponding homomorphisms.

Course Learning Outcomes: The course will enable the students to learn about:

i) The fundamental concept of Rings, Fields, subrings, integral domains and the corresponding morphisms.
ii) The concept of linear independence of vectors over a field, the idea of a finite dimensional vector space, basis of a vector space and the dimension of a vector space.
iii) Basic concepts of linear transformations, the Rank-Nullity Theorem, matrix of a linear transformation, algebra of transformations and the change of basis.

Course Contents:

Unit 1: Introduction of Rings **(Lectures: 20)**
Definition and examples of rings, Properties of rings, Subrings, Integral domains and fields, characteristic of a ring. Ideals, Ideal generated by a subset of a ring, Factor rings, Operations on ideals, Prime and maximal ideals.

Unit 2: Ring Homomorphisms **(Lectures: 10)**
Ring homomorphisms, Properties of ring homomorphisms, First, Second and Third Isomorphism theorems for rings, The Field of quotients.

Unit 3: Introduction of Vector Spaces **(Lectures: 20)**
Vector spaces, Subspaces, Algebra of subspaces, Quotient spaces, Linear combination of vectors, Linear span, Linear independence, Basis and dimension, Dimension of subspaces.

Unit 4: Linear Transformations **(Lectures: 20)**
Linear transformations, Null space, Range, Rank and nullity of a linear transformation, Matrix representation of a linear transformation, Algebra of linear transformations. Isomorphisms, Isomorphism theorems, Invertibility and the change of coordinate matrix.

References:

1. Gallian, Joseph. A. (2013). *Contemporary Abstract Algebra* (8th ed.). Cengage Learning India Private Limited. Delhi. Fourth impression, 2015.
2. Friedberg, Stephen H., Insel, Arnold J., & Spence, Lawrence E. (2003). *Linear Algebra* (4th ed.). Prentice-Hall of India Pvt. Ltd. New Delhi.

Additional Readings:

i. Dummit, David S., & Foote, Richard M. (2016). *Abstract Algebra* (3rd ed.). Student Edition. Wiley India.
ii. Herstein, I. N. (2006). *Topics in Algebra* (2nd ed.). Wiley Student Edition. India.
iii. Hoffman, Kenneth, & Kunze, Ray Alden (1978). *Linear Algebra* (2nd ed.). Prentice-Hall of India Pvt. Limited. Delhi. Pearson Education India Reprint, 2015.

Teaching Plan (BMATH410: Ring Theory & Linear Algebra-I):

Week 1: Definition and examples of rings, Properties of rings, Subrings.
[1] Chapter 12

Week 2: Integral domains and fields, Characteristic of a ring.
[1] Chapter 13

Week 3 and 4: Ideals, Ideal generated by a subset of a ring, Factor rings, Operations on ideals, Prime and maximal ideals.
[1] Chapter 14

Week 5: Ring homomorphisms, Properties of ring homomorphisms.
[1] Chapter 15 (up to Theorem 15.2)

Week 6: First, Second and Third Isomorphism theorems for rings, The Field of quotients.
[1] Chapter 15 (Theorems 15.3 to 15.6, Examples 10 to 12), and Exercises 3 and 4 on page 347.

Week 7: Vector spaces, subspaces, Algebra of subspaces.
[2] Chapter 1 (Sections 1.2, and 1.3)

Week 8: Linear combination of vectors, Linear span, Linear independence.
[2] Chapter 1 (Sections 1.4, and 1.5)

Weeks 9 and 10: Bases and dimension. Dimension of subspaces.
[2] Chapter 1 (Section 1.6)

Week 11: Linear transformations, Null space, Range, Rank and nullity of a linear transformation.
[2] Chapter 2 (Section 2.1)

Weeks 12 and 13: Matrix representation of a linear transformation, Algebra of linear transformations.
[2] Chapter 2 (Sections 2.2, and 2.3)

Week 14: Isomorphisms, Isomorphism theorems, Invertibility and the change of coordinate matrix.
[2] Chapter 2 (Sections 2.4, and 2.5)

Skill Enhancement Paper

SEC-2: Computer Algebra Systems and Related Software

Total Marks: 100 (Theory: 38, Internal Assessment: 12, and Practical: 50)
Workload: 2 Lectures, 4 Practicals (per week) **Credits:** 4 (2+2)
Duration: 14 Weeks (28 Hrs. Theory + 56 Hrs. Practical) **Examination**: 2 Hrs.

Course Objectives: This course aims at familiarizing students with the usage of computer algebra systems (/Mathematica/MATLAB/Maxima/Maple) and the statistical software **R**. The basic emphasis is on plotting and working with matrices using CAS. Data entry and summary commands will be studied in **R**. Graphical representation of data shall also be explored.

Course Learning Outcomes: This course will enable the students to:

i) Use CAS as a calculator, for plotting functions, animations and various applications of matrices.
ii) Understand the use of the software **R** for entry, summary calculation, pictorial representation of data and exploring relationship between data.
iii) Analyze, test, and interpret technical arguments on the basis of geometry.

Course Contents:

Unit 1: Introduction to CAS and Applications (Lectures: 10)
Computer Algebra System (CAS), Use of a CAS as a calculator, Computing and plotting functions in 2D, Plotting functions of two variables using Plot3D and ContourPlot, Plotting parametric curves surfaces, Customizing plots, Animating plots, Producing tables of values, working with piecewise defined functions, Combining graphics.

Unit 2: Working with Matrices (Lectures: 6)
Simple programming in a CAS, Working with matrices, Performing Gauss elimination, operations (transpose, determinant, inverse), Minors and cofactors, Working with large matrices, Solving system of linear equations, Rank and nullity of a matrix, Eigenvalue, eigenvector and diagonalization.

Unit 3: R - The Statistical Programming Language (Lectures: 6)
R as a calculator, Explore data and relationships in **R.** Reading and getting data into **R:** Combine and scan commands, Types and structure of data items with their properties. Manipulating vectors, Data frames, Matrices and lists. Viewing objects within objects. Constructing data objects and conversions.

Unit 4: Data Analysis with R (Lectures: 6)
Summary commands**:** Summary statistics for vectors, Data frames, Matrices and lists. Summary tables. Stem and leaf plot, Histograms. Plotting in **R:** Box-whisker plots, Scatter plots, Pairs plots, Line charts, Pie charts, Cleveland dot charts and bar charts. Copy and save graphics to other applications.

References:

1. Bindner, Donald & Erickson, Martin. (2011). *A Student's Guide to the Study, Practice, and Tools of Modern Mathematics*. CRC Press, Taylor & Francis Group, LLC.

2. Torrence, Bruce F., & Torrence, Eve A. (2009). *The Student's Introduction to Mathematica®: A Handbook for Precalculus, Calculus, and Linear Algebra* (2nd ed.). Cambridge University Press.
3. Gardener, M. (2012). *Beginning R: The Statistical Programming Language*, Wiley.

Additional Reading:

i. Verzani, John (2014). *Using R for Introductory Statistics* (2nd ed.). CRC Press, Taylor & Francis Group.

Note: Theoretical and Practical demonstration should be carried out only in **one** of the CAS: Mathematica/MATLAB/Maxima/Scilab or any other.

Practical/Lab work to be performed in Computer Lab.

Practicals:

[1] Chapter 12 (Exercises 1 to 4 and 8 to 12), Chapter 14 (Exercises 1 to 3)
[2] Chapter 3 [Exercises 3.2 (1 and 2), 3.3 (1, 2 and 4), 3.4 (1 and 2), 3.5 (1 to 4), 3.6 (2 and 3)].
[2] Chapter 6 (Exercises 6.2 and 6.3).
[2] Chapter 7 [Exercises 7.1 (1), 7.2, 7.3 (2), 7.4 (1) and 7.6].

Note: Relevant exercises of [3] Chapters 2 to 5 and 7 (The practical may be done on the database to be downloaded from http://data.gov.in/).

Teaching Plan (Theory of SEC-1: Computer Algebra Systems and Related Software):

Weeks 1 to 3: Computer Algebra System (CAS), Use of a CAS as a calculator, Computing and plotting functions in 2D, producing tables of values, working with piecewise defined functions, Combining graphics. Simple programming in a CAS.
[1] Chapter 12 (Sections 12.1 to 12.5)
[2] Chapter 1, and Chapter 3 (Sections 3.1 to 3.6, and 3.8)

Weeks 4 and 5: Plotting functions of two variables using Plot3D and ContourPlot, Plotting parametric curves surfaces, Customizing plots, Animating plots.
[2] Chapter 6 (Sections 6.2, and 6.3)

Weeks 6 to 8: Working with matrices, Performing Gauss elimination, operations (Transpose, Determinant, Inverse), Minors and cofactors, working with large matrices, Solving system of linear equations, Rank and nullity of a matrix, Eigenvalue, Eigenvector and diagonalization.
[2] Chapter 7 (Sections 7.1 to 7.8)

Weeks 9 to 11: R as a calculator, explore data and relationships in **R.** Reading and getting data into **R:** Combine and scan commands, Types and structure of data items with their properties. Manipulating vectors, Data frames, Matrices and Lists. Viewing objects within objects. Constructing data objects and conversions.
[1] Chapter 14 (Sections 14.1 to 14.4)
[3] Chapter 2, and Chapter 3

Weeks 12 to 14: Summary commands**:** Summary statistics for vectors, Data frames, Matrices and lists. Summary tables. Stem and leaf plot, histograms. Plotting in **R:** Box-whisker plots, Scatter plots, Pairs plots, Line charts, Pie charts, Cleveland dot charts and Bar charts. Copy and save graphics to other applications.
[1] Chapter 14 (Section 14.7)
[3] Chapter 5 (up to page 157), and Chapter 7.

Semester-V

BMATH511: Metric Spaces

Total Marks: 100 (Theory: 75, Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs,

Course Objectives: The course aims at providing the basic knowledge pertaining to metric spaces such as open and closed balls, neighborhood, interior, closure, subspace, continuity, compactness, connectedness etc.

Course Learning Outcomes: The course will enable the students to:

i) Understand the basic concepts of metric spaces;
ii) Correlate these concepts to their counter parts in real analysis;
iii) Appreciate the abstractness of the concepts such as open balls, closed balls, compactness, connectedness etc. beyond their geometrical imaginations.

Course Contents:

Unit 1: Basic Concepts (Lectures: 15)
Metric spaces**:** Definition and examples, Sequences in metric spaces, Cauchy sequences, Complete metric space.

Unit 2: Topology of Metric Spaces (Lectures: 25)
Open and closed ball, Neighborhood, Open set, Interior of a set, limit point of a set, derived set, closed set, closure of a set, diameter of a set, Cantor's theorem, Subspaces, Dense set.

Unit 3: Continuity & Uniform Continuity in Metric Spaces (Lectures: 15)
Continuous mappings, Sequential criterion and other characterizations of continuity, Uniform continuity, Homeomorphism, Contraction mapping, Banach fixed point theorem.

Unit 4: Connectedness and Compactness (Lectures: 15)
Connectedness, Connected subsets of $\mathbb{R}$, Connectedness and continuous mappings, Compactness, Compactness and boundedness, Continuous functions on compact spaces.

Reference:

1. Shirali, Satish & Vasudeva, H. L. (2009). *Metric Spaces*, Springer, First Indian Print.

Additional Readings:

i. Kumaresan, S. (2014). *Topology of Metric Spaces* (2nd ed.). Narosa Publishing House. New Delhi.
ii. Simmons, George F. (2004). *Introduction to Topology and Modern Analysis*. McGraw-Hill Education. New Delhi.

Teaching Plan (BMATH511: Metric Spaces):

Week 1: Definition of metric space, Illustration using the usual metric on $\mathbb{R}$, Euclidean and max metric on $\mathbb{R}^2$, Euclidean and max metric on $\mathbb{R}^n$, Discrete metric, Sup metric on $\boldsymbol{B}(S)$ and $\boldsymbol{C}[a, b]$, Integral metric on $\boldsymbol{C}[a, b]$ etc.
[1] Chapter 1 [Section 1.2 (1.2.1, 1.2.2 ((i), (ii), (iv), (v), (viii), (ix), (x)), 1.2.3, and 1.2.4 (i))]

Week 2: Sequences in metric space, Definition of limit of a sequence, Illustration through examples, Cauchy sequences.
[1] Chapter 1 [Section 1.3 (1.3.1, 1.3.2, 1.3.3 ((i), (iv)), 1.3.5), Section 1.4 (1.4.1 to 1.4.4)]

Week 3: Definition of complete metric spaces, Illustration through examples.
[1] Chapter 1 [Section 1.4 (1.4.5 to 1.4.7, 1.4.12 to 1.4.14(ii))]

Week 4: Open and closed balls, Neighborhood, Open sets, Examples and basic results.
[1] Chapter 2 [Section 2.1 (2.1.1 to 2.1.11 (except 2.1.6(ii)))]

Week 5: Interior point, Interior of a set, Limit point, Derived set, Examples and basic results.
[1] Chapter 2 [Section 2.1 (2.1.12 to 2.1.20)]

Week 6: Closed set, Closure of a set, Examples and basic results.
[1] Chapter 2 [Section 2.1 (2.1.21 to 2.1.35)]

Week 7: Bounded set, Diameter of a set, Cantor's theorem.
[1] Chapter 2 [Section 2.1 (2.1.41 to 2.1.44)]

Week 8: Relativisation and subspaces, Dense sets.
[1] Chapter 2 [Section 2.2 (2.2.1 to 2.2.6), Section 2.3 (2.3.12 to 2.3.13(iv))]

Weeks 9 to 11: Continuous mappings, Sequential and other characterizations of continuity, Uniform continuity, Homeomorphism, Contraction mappings, Banach fixed point theorem.
[1] Chapter 3 [Section 3.1, Section 3.4 (3.4.1 to 3.4.8), Section 3.5 (3.5.1 to 3.5.7(iii)), and Section 3.7 (3.7.1 to 3.7.5)]

Weeks 12 to 14: Connectedness and compactness, Definitions and properties of connected and compact spaces.
[1] Chapter 4 [Section 4.1 (4.1.1 to 4.1.12)], and Chapter 5 [Section 5.1 (5.1.1 to 5.1.6), and Section 5.3 (5.3.1 to 5.3.10)]

BMATH512: Group Theory-II

Total Marks: 100 (Theory: 75, Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination**: 3 Hrs.

Course Objectives: The course will develop an in-depth understanding of one of the most important branch of the abstract algebra with applications to practical real-world problems. Classification of all finite Abelian groups (up to isomorphism) can be done.

Course Learning Outcomes: The course shall enable students to learn about:

i) Automorphisms for constructing new groups from the given group.
ii) External direct product $Z_2 \oplus Z_2$ applies to data security and electric circuits.
iii) Group actions, Sylow theorems and their applications to check nonsimplicity.

Course Contents:

Unit 1: Automorphisms and Properties (Lectures: 10)
Automorphism, inner automorphism, Automorphism groups, Automorphism groups of finite and infinite cyclic groups, Characteristic subgroups, Commutator subgroup and its properties; Applications of factor groups to automorphism groups.

Unit 2: External and Internal Direct Products of Groups (Lectures: 15)
External direct products of groups and its properties, The group of units modulo *n* as an external direct product, Applications to data security and electric circuits; Internal direct products, Classification of groups of order p^2, where *p* is a prime; Fundamental theorem of finite Abelian groups and its isomorphism classes.

Unit 3: Group Action (Lectures: 20)
Group actions and permutation representations; Stabilizers and kernels of group actions; Groups acting on themselves by left multiplication and consequences; Conjugacy in S_n.

Unit 4: Sylow Theorems and Applications (Lectures: 25)
Conjugacy classes, The class equation, *p*-groups, The Sylow theorems and consequences, Applications of Sylow theorems; Finite simple groups, Nonsimplicity tests; Generalized Cayley's theorem, Index theorem, Embedding theorem and applications. Simplicity of A_5.

References:

1. Dummit, David S., & Foote, Richard M. (2016). *Abstract Algebra* (3rd ed.). Student Edition. Wiley India.
2. Gallian, Joseph. A. (2013). *Contemporary Abstract Algebra* (8th ed.). Cengage Learning India Private Limited. Delhi. Fourth impression, 2015.

Additional Reading:

i. Rotman, Joseph J. (1995). *An Introduction to The Theory of Groups* (4th ed.). Springer Verlag, New York.

Teaching Plan (BMATH512: Group Theory-II):

Week 1: Automorphism, Inner automorphism, Automorphism groups, Automorphism groups of finite and infinite cyclic groups.
[2] Chapter 6 (pages 135 to 138)

Week 2: Characteristic subgroups, Commutator subgroup and its properties; Applications of factor groups to automorphism groups.
[2] Exercises 1 to 4 on page 181, and Exercises 62, 68 on page 204.
[2] Chapter 9 (Theorem 9.4 and Example 17)

Week 3: External direct products of groups and its properties, The group of units modulo *n* as an external direct product, Applications to data security and electric circuits.
[2] Chapter 8

Week 4: Internal direct products, Classification of groups of order p^2, where *p* is a prime.
[2] Chapter 9 (Section on internal direct products, pages 195 to 200)

Week 5: Statement of th**e** Fundamental theorem of finite Abelian groups, The isomorphism classes of Abelian groups.
[2] Chapter 11

Weeks 6 and 7: Group actions and permutation representations; Stabilizers and kernels of group actions.
[1] Chapter 1 (Section 1.7), Chapter 2 (Section 2.2), and Chapter 4 (Section 4.1, except cycle decompositions)

Weeks 8 and 9: Groups acting on themselves by left multiplication and consequences;
Conjugacy in S_n.
[1] Chapter 4 [Section 4.2, and Section 4.3 (Pages 125-126)]

Week 10: Conjugacy classes, The class equation, *p*-groups.
[2] Chapter 24 (Pages 409 to 411)

Weeks 11 and 12: State three Sylow theorems and give their applications.
[2] Chapter 24 (Pages 412 to 421)

Weeks 13 and 14: Finite simple groups, Nonsimplicity tests; Generalized Cayley's theorem, Index theorem, Embedding theorem and applications; Simplicity of A_5.
[2] Chapter 25

Discipline Specific Elective (DSE) Course -1 (including practicals)

Any *one* of the following (at least *two* shall be offered by the college):

DSE-1 (i): Numerical Analysis
DSE-1 (ii): Mathematical Modeling and Graph Theory
DSE-1 (iii): C++ Programming for Mathematics

DSE-1 (i): Numerical Analysis

Total Marks: 150 (Theory: 75 + Internal Assessment: 25 + Practical: 50)
Workload: 4 Lectures, 4 Periods practical (per week) **Credits:** 6 (4+2)
Duration: 14 Weeks (56 Hrs. Theory + 56 Hrs. practical) **Examination:** 3 Hrs.

Course Objectives: To comprehend various computational techniques to find approximate value for possible root(s) of non-algebraic equations, to find the approximate solutions of system of linear equations and ordinary differential equations. Also, the use of Computer Algebra System (CAS) by which the numerical problems can be solved both numerically and analytically, and to enhance the problem solving skills.

Course Learning Outcomes: The course will enable the students to learn the following:

i) Some numerical methods to find the zeroes of nonlinear functions of a single variable and solution of a system of linear equations, up to a certain given level of precision.
ii) Interpolation techniques to compute the values for a tabulated function at points not in the table.
iii) Applications of numerical differentiation and integration to convert differential equations into difference equations for numerical solutions.

Course Contents:

Unit 1: Methods for Solving Algebraic and Transcendental Equations (Lectures: 16)
Algorithms, Convergence, Bisection method, False position method, Fixed point iteration method, Newton's method, Secant method

Unit 2:Techniques to Solve Linear Systems (Lectures: 12)
Partial and scaled partial pivoting, LU decomposition and its applications, Iterative methods: Gauss-Jacobi, Gauss-Seidel and SOR methods.

Unit 3: Interpolation (Lectures: 12)
Lagrange and Newton interpolation, Piecewise linear interpolation.

Unit 4: Numerical Differentiation and Integration (Lectures: 16)
First order and higher order approximation for first derivative, Approximation for second derivative. Numerical integration by closed Newton-Cotes formula: trapezoidal rule, Simpson's rule and its error analysis. Euler’s method to solve ODE’s.

Note: Emphasis is to be laid on the algorithms of the above numerical methods.

Reference:

1. Bradie, Brian. (2006). *A Friendly Introduction to Numerical Analysis*. Pearson Education, India. Dorling Kindersley (India) Pvt. Ltd. Third impression 2011.

Additional Readings:

i. Jain, M. K., Iyengar, S. R. K., & Jain, R. K. (2012). *Numerical Methods for Scientific and Engineering Computation*. (6th ed.). New Age International Publisher, India, 2016.
ii. Gerald, C. F., & Wheatley, P. O. (2008). *Applied Numerical Analysis* (7th ed.). Pearson Education. India.

Practical/Lab work to be performed in Computer Lab:

Use of computer algebra software (CAS), for example Mathematica/MATLAB/Maple/ Maxima/Scilab etc., for developing the following numerical programs:

(1) Bisection method
(2) Newton Raphson method
(3) Secant method
(4) Regula Falsi method
(5) LU decomposition method
(6) Gauss-Jacobi method
(7) SOR method
(8) Gauss-Seidel method
(9) Lagrange interpolation
(10) Newton interpolation
(11) Trapezoidal rule
(12) Simpson's rule
(13) Euler's method

Note: For any of the CAS: Mathematica /MATLAB/ Maple/Maxima /Scilab etc., data types-simple data types, floating data types, character data types, arithmetic operators and operator precedence, variables and constant declarations, expressions, input/output, relational operators, logical operators and logical expressions, control statements and loop statements, Arrays should be introduced to the students.

Teaching Plan (Theory of DSE-l (i): Numerical Analysis):

Week 1: Algorithms, Convergence, Order of convergence and examples.
[1] Chapter 1 (Sections 1.1, and 1.2)

Week 2: Bisection method, False position method and their convergence analysis, Stopping condition and algorithms.
[1] Chapter 2 (Sections 2.1, and 2.2)

Week 3: Fixed point iteration method, its order of convergence and stopping condition.
[1] Chapter 2 (Section 2.3)

Week 4: Newton's method, Secant method, their order of convergence and convergence analysis.
[1] Chapter 2 (Sections 2.4, and 2.5)

Week 5: Examples to understand partial and scaled partial pivoting. LU decomposition.
[1] Chapter 3 (Sections 3.2, and 3.5, up to Example 3.15)

Weeks 6 and 7: Application of LU decomposition to solve system of linear equations. Gauss-Jacobi method, Gauss-Seidel and SOR iterative methods to solve system of linear equations.
[1] Chapter 3 (Sections 3.5, and 3.8)

Week 8: Lagrange interpolation**:** Linear and higher order interpolation, and error in it.
[1] Chapter 5 (Section 5.1)

Weeks 9 and 10: Divided difference and Newton interpolation. Piecewise linear interpolation.
[1] Chapter 5 (Sections 5.3, and 5.5)

Weeks 11 and 12: First order and higher order approximation for first derivative and error in the approximation. Second order forward, Backward and central difference approximations for second derivative.
[1] Chapter 6 (Section 6.2)

Week 13: Numerical integration**:** Trapezoidal rule, Simpson's rule and its error analysis.
[1] Chapter 6 (Section 6.4)

Week 14: Euler's method to solve first order ODE initial value problems.
[1] Chapter 7 (Section 7.2 up to page 562)

DSE-1 (ii): Mathematical Modeling and Graph Theory

Total Marks: 150 (Theory: 75 + Internal Assessment: 25 + Practical: 50)
Workload: 4 Lectures, 4 Periods practical (per week) **Credits:** 6 (4+2)
Duration: 14 Weeks (56 Hrs. Theory + 56 Hrs. practical) **Examination:** 3 Hrs.

Course Objectives: The main objective of this course is to teach students how to model physical problems using differential equations and solve them. Also, the use of Computer Algebra Systems (CAS) by which the listed problems can be solved both numerically and analytically.

Course Learning Outcomes: The course will enable the students to learn the following:

i) The use of mathematics software to observe the implementations of the above mentioned methods efficiently, and to enhance the problem solving skills.
ii) To solve physical problems using differential equations.

Course Contents:

Unit 1: Power Series Solutions **(Lectures: 16)**
Power series solution of a differential equation about an ordinary point, Solution about a regular singular point, The method of Frobenius. Legendre's and Bessel's equation.

Unit 2: Laplace Transforms **(Lectures: 8)**
Laplace transform and inverse transform, application to initial value problem up to second order.

Unit 3: Monte Carlo Simulation **(Lectures: 16)**
Monte Carlo Simulation Modeling**:** Simulating deterministic behavior (area under a curve, volume under a surface); Generating Random Numbers**:** Middle square method, Linear congruence; Queuing Models**:** Harbor system, Morning rush hour. Overview of optimization modeling; Linear Programming Model: Geometric solution, Algebraic solution, Simplex method, Sensitivity analysis.

Unit 4: Graph Theory **(Lectures: 16)**
Graphs, Diagraphs, Networks and subgraphs, Vertex degree, Paths and cycles, Regular and bipartite graphs, Four cube problem, Social networks, Exploring and traveling, Eulerian and Hamiltonian graphs, Applications to dominoes, Diagram tracing puzzles, Knight's tour problem, Gray codes.

References:

1. Aldous, Joan M., & Wilson, Robin J. (2007). *Graphs and Applications*: *An Introductory Approach*. Springer. Indian Reprint.
2. Edwards, C. Henry, Penney, David E., & Calvis, David T. (2015). *Differential Equation and Boundary Value Problems*: *Computing and Modeling* (5th ed.). Pearson.
3. Giordano, Frank R., Fox, William P., & Horton, Steven B. (2014). *A First Course in Mathematical Modeling* (5th ed.). Brooks/Cole, Cengage Learning.

Practical / Lab work to be performed in Computer Lab:

Modeling of the following problems using Mathematica/MATLAB/Maple /Maxima/Scilab etc.

(i). Plotting of Legendre polynomial for n = 1 to 5 in the interval [0, 1]. Verifying graphically that all the roots of $P_n(x)$ lie in the interval [0, 1].

(ii). Automatic computation of coefficients in the series solution near ordinary points.

(iii). Plotting of the Bessel's function of first kind of order 0 to 3.

(iv). Automating the Frobenius Series Method.

(v). Random number generation and then use it for one of the following:
- a) Simulate area under a curve.
- b) Simulate volume under a surface.

(vi). Programming of either one of the queuing model:
- a) Single server queue (e.g. Harbor system).
- b) Multiple server queue (e.g. Rush hour).

(vii). Programming of the Simplex method for 2 / 3 variables.

Teaching Plan (Theory of DSE-l (ii): Mathematical Modeling and Graph Theory):

Weeks 1 and 3: Power series solution of a differential equation about an ordinary point, Solution about a regular singular point. Legendre's equation. The method of Frobenius.
[2] Chapter 8 (Sections 8.1 to 8.3)

Week 4: Bessel's equation. Bessel's function of first kind.
[2] Chapter 8 [Section 8.5 up to Equation (19), page 551)]

Weeks 5 and 6: Laplace transform and inverse transform, Application to initial value problem up to second order.
[2] Chapter 7 (Sections 7.1 to 7.3)

Weeks 7 and 8: Monte Carlo Simulation Modeling**:** Simulating deterministic behavior (area under a curve, volume under a surface), Generating Random Numbers**:** Middle square method, Linear congruence. Queuing Models**:** Harbor system, Morning rush hour.
[3] Chapter 5 (Sections 5.1 to 5.2, and 5.5)

Weeks 9 and 10: Overview of optimization modeling, Linear Programming Model: Geometric solution, Algebraic solution, Simplex method, Sensitivity analysis.
[3] Chapter 7

Weeks 11 and 12: Graphs, Diagraphs, Networks and subgraphs, Vertex degree, Paths and cycles, Regular and bipartite graphs, Four cube problem, Social networks.
[1] Chapter 1 (Section 1.1), and Chapter 2

Weeks 13 and 14: Overview of optimization modeling, Linear Programming Model: Geometric solution, Algebraic solution, Simplex method, Sensitivity analysis.
[1] Chapter 3

Note: [1] Chapter 1 (Section 1.1), Chapter 2 (Sections 2.1 to 2.4), Chapter 3 (Sections 3.1 to 3.3) are to be reviewed only. This is in order to understand the models on Graph Theory.

DSE-1 (iii): C++ Programming for Mathematics

Total Marks: 150 (Theory: 75 + Internal Assessment: 25 + Practical: 50)
Workload: 4 Lectures, 4 Periods practical (per week) **Credits:** 6 (4+2)
Duration: 14 Weeks (56 Hrs. Theory + 56 Hrs. practical) **Examination:** 3 Hrs.

Course Objectives: This course introduces C++ programming in the idiom and context of mathematics and imparts a starting orientation using available mathematical libraries, and their applications.

Course Learning Outcomes: After completion of this paper, student will be able to:

i) Understand and apply the programming concepts of C++ which is important to mathematical investigation and problem solving.
ii) Use mathematical libraries for computational objectives.
iii) Represent the outputs of programs visually in terms of well formatted text and plots.

Course Contents:

Unit 1: C++ Essentials (Lectures: 16)
Fundamentals of programming, Organization of logic flow in stored program model of computation, C++ as a general purpose programming language, Structure of a C++ program, Common compilers and IDE's, Basic data-types, Variables and literals in C++, Operators, Expressions, Evaluation precedence, and Type compatibility. Outline of program development in C++, Debugging and testing.
Applications**:** Greatest common divisor, and Random number generation.

Unit 2: Working with Structured Data (Lectures: 12)
Structured data-types in C++, Arrays and manipulating data in arrays with applications in factorization of an integer and finding Euler's totient; Objects and classes**:** Information hiding, Modularity, Constructors and Destructors, Methods and Polymorphism.
Applications**:** Cartesian geometry using points (2 & 3-dimensional), and Pythagorean triples.

Unit 3: Working with Containers and Templates (Lectures: 16)
Containers and Template Libraries**:** Sets, Iterators, Multisets, Vectors, Maps, Lists, Stacks and Queues. Applications**:** Basic set algebra, Modulo arithmetic, Permutations, and Polynomials.

Unit 4: Using Mathematical Libraries and Packages (Lectures: 12)
Arbitrary precision arithmetic using the GMP package; Linear algebra**:** Two-dimensional arrays in C++ with applications in finding Eigenvalues, Eigenvectors, Rank, Nullity, and Solving system of linear equations in matrices. Features of C++ for input/output and visualization**:** Strings, Streams, Formatting methods, Processing files in a batch, Command-line arguments, Visualization packages and their use in plots.

Reference:

1. Scheinerman, Edward (2006). *C++ for Mathematicians*: *An Introduction for Students and Professionals*. Chapman & Hall/CRC. Taylor & Francis Group, LLC.

Additional Readings:

i. Dale, Nell & Weems, Chip (2013). *Programming and Problem Solving with C++* (6th ed.). Comprehensive Edition. Jones & Bartlett Learning.
ii. Gottschling, Peter (2016). *Discovering Modern C++*: *An Intensive Course for Scientists, Engineers, and Programmers*. Addison-Wesley. Pearson Education, Inc.
iii. Josuttis, Nicolai M. (2012). *The C++ Standard Library*: *A Tutorial and Reference* (2nd ed.). Addison-Wesley. Pearson Education, Inc.
iv. Lippman, Stanley B. (2000). *Essential C++*. Addison-Wesley.
v. Stroustrup, Bjarne (2013). *The C++ Programming Language* (4^{th} ed.). Addison-Wesley.

Practical / Lab work to be performed in Computer Lab:

A: Preparatory (Practical Sessions: 8 Hrs.)

1. Setting up of C++ programming environment on Linux/Windows/Mac-OS; gcc/g++/mingw/cc, Program-development methodology and use IDE's or other tools.
2. Demonstration of sample programs for
   a. "Hello World"
   b. Sum of an arithmetic progression.
   c. Value of $\sin x$ using series expansion.
3. Finding/demonstrating:
   a. Machine epsilon.
   b. Integer and float overflow/underflow.
   c. Iteration and selection based logic.
   (provide a list of 8-10 problems suitable to learners needs)

B: Evaluative:

Set-I: (Practical Sessions: 8 Hrs.)

1. Greatest common divisor (including Euclid's Method).
2. Random number generation (including a Monte Carlo Program).

Set-II: (Practical Sessions: 12 Hrs.)

1. Factorization of an integer, and Euler's totient.
2. Cartesian geometry using points (2 & 3-dimensional).
3. Pythagorean triples.

Set-III: (Practical Sessions: 16 Hrs.)

1. Basic set algebra.
2. Modulo arithmetic.
3. Permutations.
4. Polynomials.

Set-IV: (Practical Sessions: 12 Hrs.)

1. Arbitrary precision arithmetic using the GMP package.
2. Finding Eigenvalues, Eigenvectors, Rank, Nullity, and Solving system of linear equations in matrices.
3. Plots (using the GNU plotutils package).

Note. *Exception handling in lab-exercises* (SET-I to IV), *Comments/Documentation using Doxygen may be emphasized.*

Teaching Plan (Theory of DSE-1 (iii) C++ Programming for Mathematics):

Week 1: Fundamentals of programming, Organization of logic flow in stored program model of computation, C++ as a general purpose programming language, Structure of a C++ program, Common compilers and IDE's, Basic data-types.
[1] Chapter 1, and Chapter 2 (Sections 2.1 to 2.3)

Week 2: Variables and literals in C++, Operators, Expressions, Evaluation precedence, and Type compatibility. Outline of program development in C++, Debugging and testing.
[1] Chapter 2 (Sections 2.4 to 2.9)

Weeks 3 and 4: Applications**:** Greatest common divisor, and Random number generation.
[1] Chapter 3, and Chapter 4

Week 5: Structured data-types in C++, Arrays and manipulating data in arrays.
Applications**:** Factorization of an integer, and Euler's totient.
[1] Chapter 5 (Sections 5.1 to 5.4)

Weeks 6 and 7: Objects and classes**:** Information hiding, Modularity, Constructors and Destructors, Methods and Polymorphism. Applications**:** Cartesian geometry using points (two and three dimensional), and Pythagorean triples.
[1] Chapter 6, and Chapter 7

Weeks 8 and 9: Containers and Template Libraries**:** Sets, Iterators, Multisets, Vectors, Maps, Lists, Stacks and Queues with applications in basic set algebra.
[1] Chapter 8 [Sections 8.1 to 8.7 (8.7.1 – 8.7.3)]

Weeks 10 and 11: Applications**:** Modulo arithmetic, Permutations, and Polynomials.
[1] Chapter 9, Chapter 11 (Sections 11.1, and 11.2), and Chapter 12 (Sections 12.1 to 12.3)

Week 12: Arbitrary precision arithmetic using the GMP package; Linear algebra**:** Two-dimensional arrays in C++ with applications in finding Eigenvalues, Eigenvectors, Rank, Nullity, and Solving system of linear equations in matrices.
[1] Chapter 13 [Sections 13.1, and 13.2 (13.2.1, 13.2.2)]

Weeks 13 and 14: Features of C++ for input/output & visualization**:** Strings, Streams, Formatting methods, Processing files in a batch, Command-line arguments, Visualization packages and their use in plots.
[1] Chapter 14 [Sections 14.1 to 14.6, and 14.8 (14.8.1-14.8.3)]

Discipline Specific Elective (DSE) Course - 2

Any *one* of the following (at least *two* shall be offered by the college):

DSE-2 (i): Probability Theory and Statistics
DSE-2 (ii): Discrete Mathematics
DSE-2 (iii): Cryptography and Network Security

DSE-2 (i): Probability Theory and Statistics

Total Marks: 100 (Theory: 75 + Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: To make the students familiar with the basic statistical concepts and tools which are needed to study situations involving uncertainty or randomness. The course intends to render the students to several examples and exercises that blend their everyday experiences with their scientific interests.

Course Learning Outcomes: This course will enable the students to learn:

i) Distributions to study the joint behavior of two random variables.
ii) To establish a formulation helping to predict one variable in terms of the other, i.e., correlation and linear regression.
iii) Central limit theorem, which helps to understand the remarkable fact that**:** the empirical frequencies of so many natural populations, exhibit a bell shaped curve.

Course Contents:

Unit 1: Probability Functions and Moment Generating Function (Lectures: 20)
Sample space, Probability set function, Real random variables - Discrete and continuous, Cumulative distribution function, Probability mass/density functions, Transformations, Mathematical expectation, Moments, Moment generating function, Characteristic function.

Unit 2: Univariate Discrete and Continuous Distributions (Lectures: 20)
Discrete distributions**:** Uniform, Bernoulli, Binomial, Negative binomial, Geometric and Poisson; Continuous distributions**:** Uniform, Gamma, Exponential, Chi-square, Beta and normal; Normal approximation to the binomial distribution.

Unit 3: Bivariate Distribution (Lectures: 10)
Joint cumulative distribution function and its properties, Joint probability density function, Marginal distributions, Expectation of function of two random variables, Joint moment generating function, Conditional distributions and expectations.

Unit 4: Correlation, Regression and Central Limit Theorem (Lectures: 20)
The Correlation coefficient, Covariance, Calculation of covariance from joint moment generating function, Independent random variables, Linear regression for two variables, The method of least squares, Bivariate normal distribution, Chebyshev's theorem, Strong law of large numbers, Central limit theorem and weak law of large numbers.

References:

1. Hogg, Robert V., McKean, Joseph W., & Craig, Allen T. (2013). *Introduction to Mathematical Statistics* (7th ed.). Pearson Education, Inc.
2. Miller, Irwin & Miller, Marylees. (2014). John E. Freund's *Mathematical Statistics with Applications* (8th ed.). Pearson. Dorling Kindersley (India).
3. Ross, Sheldon M. (2014). *Introduction to Probability Models* (11th ed.). Elsevier Inc.

Additional Reading:

i. Mood, A. M., Graybill, F. A. & Boes, D. C. (1974). *Introduction to the Theory of Statistics* (3rd ed.). McGraw-Hill Education Pvt. Ltd. Indian Edition (2017).

Teaching Plan (DSE-2 (i): Probability Theory and Statistics):

Weeks 1 and 2: Sample space, Probability set function and examples, Random variable, Probability mass/density function, Cumulative distribution function and its properties.
[1] Chapter 1 (Sections 1.1, 1.3, and 1.5)

Week 3 and 4: Discrete and continuous random variables, and Transformations. Expectation of random variables, and some special expectations**:** Mean, Variance, Standard deviation, Moments and moment generating function, Characteristic function.
[1] Chapter 1 (Sections 1.6 to 1.9)

Week 5: The discrete distributions - Uniform, Bernoulli and binomial.
[2] Chapter 5 (Sections 5.2 to 5.4)

Week 6: The discrete distributions - negative Binomial, Geometric and Poisson.
[2] Chapter 5 (Sections 5.5, and 5.7)

Week 7: The continuous distributions **-** Uniform, Gamma, Exponential, Chi-square and Beta.
[2] Chapter 6 (Sections 6.2 to 6.4)

Week 8: Normal distribution, and normal approximation to the binomial distribution.
[2] Chapter 6 (Sections 6.5, and 6.6)

Weeks 9 and 10: Random vector**:** Discrete and continuous, Joint cumulative distribution function and its properties, Joint probability mass/density function, Marginal probability mass function, and expectation of two random variables, Joint moment generating function, Conditional distributions and expectations.
[1] Chapter 2 (Sections 2.1, and 2.3)

Week 11: The Correlation coefficient, Covariance, Calculation of covariance from joint moment generating function, Independent random variables.
[1] Chapter 2 (Section 2.4, and Section 2.5)

Week 12: Linear regression for two variables, and the method of least squares.
[2] Chapter 14 (Sections 14.1 to 14.3)

Week 13: Bivariate normal distribution; Chebyshev's theorem.
[2] Chapter 6 (Section 6.7), and Chapter 4 (Section 4.4)

Week 14: Statement and interpretation of the strong law of large numbers, Central limit theorem and the weak law of large numbers.
[3] Chapter 2 (Section 2.8, and Exercise 76, page 89)

DSE-2 (ii): Discrete Mathematics

Total Marks: 100 (Theory: 75 + Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: This course aims at introducing the concepts of lattices, Boolean algebras, switching circuits and graph theory. The course discusses some important applications of Boolean algebra and graph theory in real life situations through switching circuits and shortest path algorithms.

Course Learning outcomes: After the course, the student will be able to understand the concepts of:

i) Lattices and their types;
ii) Boolean algebra, switching circuits and their applications;
iii) Graphs, their types and its applications in study of shortest path algorithms.

Course Contents:

Unit 1: Ordered Sets **(Lectures: 10)**
Definitions, Examples and basic properties of ordered sets, Order isomorphism, Hasse diagrams, Dual of an ordered set, Duality principle, Maximal and minimal elements, Building new ordered sets, Maps between ordered sets.

Unit 2: Lattices **(Lectures: 20)**
Lattices as ordered sets, Lattices as algebraic structures, Sublattices, Products and homomorphisms; Definitions, Examples and properties of modular and distributive lattices, The $M_3 - N_5$ Theorem with applications, Complemented lattice, Relatively complemented lattice, Sectionally complemented lattice.

Unit 3: Boolean Algebras and Switching Circuits **(Lectures: 20)**
Boolean Algebras, De Morgan's laws, Boolean homomorphism, Representation theorem; Boolean polynomials, Boolean polynomial functions, Disjunctive normal form and conjunctive normal form, Minimal forms of Boolean polynomial, Quinn-McCluskey method, Karnaugh diagrams, Switching circuits and applications of switching circuits.

Unit 4: Graph Theory **(Lectures: 20)**
Introduction to graphs, Konigsberg Bridge problem, Instant insanity game; Definition, examples and basic properties of graphs, Subgraphs, Pseudographs, Complete graphs, Bipartite graphs, Isomorphism of graphs, Paths and circuits, Eulerian circuits, Hamiltonian cycles, Adjacency matrix, Weighted graph, Travelling salesman problem, Shortest path, Dijkstra's algorithm.

References:

1. Davey, B. A., & Priestley, H. A. (2002). *Introduction to Lattices and Order* (2nd ed.). Cambridge University press, Cambridge.

2. Goodaire, Edgar G., & Parmenter, Michael M. (2011). *Discrete Mathematics with Graph Theory* (3rd ed.). Pearson Education (Singapore) Pvt. Ltd. Indian Reprint.
3. Lidl, Rudolf & Pilz, Gunter. (2004). *Applied Abstract Algebra* (2nd ed.), Undergraduate Texts in Mathematics. Springer (SIE). Indian Reprint.

Additional Reading:

i. Rosen, Kenneth H. (2012). *Discrete Mathematics and its Applications, with Combinatorics and Graph Theor*y. (7th ed.). McGraw-Hill Education. Indian Reprint.

Teaching Plan (DSE-2 (ii): Discrete Mathematics):

Weeks 1 and 2: Definitions, Examples and basic properties of ordered sets, Order isomorphism, Hasse diagrams, dual of an ordered set, Duality principle, Maximal and minimal elements, Building new ordered sets, Maps between ordered sets.
[1] Chapter 1 (Sections 1.1 to 1.5 and 1.14 to 1.26, and 1.34 to 1.36)
[3] Chapter 1 [Section 1 (1.1 to 1.3)]

Weeks 3 and 4: Lattices as ordered sets, Lattices as algebraic structures, Sublattices, Products and homomorphisms.
[1] Chapter 2 (Sections 2.1 to 2.19)
[3] Chapter 1 [Section 1 (1.5 to 1.20)]

Week 5: Definitions, Examples and properties of Modular and Distributive lattices.
[1] Chapter 4 (Sections 4.1 to 4.9)
[3] Chapter 1 [Section 2 (2.1 to 2.6).

Week 6: $M_3 – N_5$ Theorem with applications, Complemented lattice, Relatively complemented lattice, sectionally complemented lattice.
[1] Chapter 4 (Sections 4.10, and 4.11)
[3] Chapter 1 [Section 2 (2.7 to 2.14)]

Weeks 7 and 8: Boolean Algebras, De Morgan's laws, Boolean homomorphism, representation theorem. Boolean polynomials, Boolean polynomial functions, Disjunctive normal form and conjunctive normal form.
[3] Chapter 1 (Sections 3, and 4)

Week 9: Minimal forms of Boolean polynomial, Quinn-McCluskey method, Karnaugh diagrams.
[3] Chapter 1 (Section 6)

Week 10: Switching circuits and applications of switching circuits.
[3] Chapter 2 (Sections 7, and 8).

Weeks 11 and 12: Introduction to graphs, Konigsberg Bridge problem, Instant insanity game. Definition, Examples and basic properties of graphs, Subgraphs, Pseudographs, Complete graphs, Bipartite graphs, Isomorphism of graphs.
[2] Chapter 9 [Sections 9.1, 9.2 (9.2.1, 9.2.7), and 9.3]

Weeks 13 and 14: Paths and circuits, Eulerian circuits, Hamiltonian cycles, Adjacency matrix, Weighted graph, Travelling salesman problem, shortest path, Dijkstra's algorithm.
[2] Chapter 10 [Sections 10.1 to 10.4 (10.4.1 to 10.4.3)]

DSE-2 (iii): Cryptography and Network Security

Total Marks: 100 (Theory: 75 + Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: This course helps the students to develop skills and knowledge of standard concepts in cryptography and demonstrates how cryptography plays an important role in the present digital world by knowing encryption and decryption techniques and secure data in transit across data networks.

Course Learning Outcomes: After the course, the student will be able to:

i) Understand the fundamentals of Cryptography and Network Security, including data and advanced encryption standard (DES & AES), RSA and elliptic curve cryptography.

ii) Encrypt and decrypt messages using block ciphers, sign and verify messages using well known signature generation and verification algorithms.

iii) Acquire knowledge of standard algorithms that can be used to provide confidentiality, integrity and authentication of data.

Course Contents:

Unit 1: Cryptography and Data Encryption Standard (DES) (Lectures: 20)
Overview of Cryptography, Computer security concepts, Security attacks, Symmetric cipher model, Cryptanalysis and brute-force attack, Substitution techniques, Caesar cipher, Monoalphabetic ciphers, Playfair cipher, Hill cipher, Polyalphabetic ciphers, One-time pad, Transposition techniques, Binary and ASCII, Pseudo-random bit generation, Stream ciphers and Block ciphers, The Feistal cipher, The data encryption standard (DES), DES example.

Unit 2: Algorithms and Advanced Encryption Standard (AES) (Lectures: 20)
Review of basic concepts in Number theory and Finite Fields**:** Divisibility, Polynomial and modular arithmetic, Fermat's and Euler's theorems, The Chinese remainder theorem, Discrete logarithm., Finite fields of the form GF(p) and GF(2^n). Advanced encryption standard (AES), AES transformation functions, AES key expansion, AES example.

Unit 3: Public-key Cryptography (Lectures: 15)
Principles of public-key cryptosystems, The RSA algorithm and security of RSA, Elliptic curve arithmetic, Elliptic curve cryptography, Cryptographic Hash functions, Secure Hash algorithm.

Unit 4: Digital Signatures and Network Security (Lectures: 15)
Digital signatures, Elgamal and Schnorr digital signature schemes, Digital signature algorithm. Wireless network and mobile device security, Email architecture, formats, threats and security, Secure/Multipurpose Internet Mail Extension (S/MIME) and Pretty Good Privacy (PGP).

References:

1. Stallings, William (2017). *Cryptography and Network Security, Principles and Practice* (7th ed.). Pearson Education Limited. England.

2. Trappe, Wade & Washington, Lawrence C. (2006). *Introduction to Cryptography with Coding Theory* (2nd ed.). Pearson Education International.

Additional Reading:

i. Stinson, Douglas R. (2005). *Cryptography Theory and Practice* (3rd ed.). CRC Press.

Teaching Plan (DSE-2 (iii): Cryptography and Network Security):

Weeks 1 and 2: Overview of Cryptography, Computer security concepts, Security attacks, Symmetric cipher model, Cryptanalysis and brute-force attack, Substitution techniques, Caesar cipher, Monoalphabetic ciphers, Playfair cipher, Hill cipher, Polyalphabetic ciphers, One-time pad.
[2] Chapter 1
[1] Chapter 1 (Sections 1.1, and 1.3), Chapter 3 (Sections 3.1, 3.2)

Weeks 3 and 4: Transposition techniques, Binary and ASCII, Pseudo-random bit generation, Stream ciphers and Block ciphers, The Feistal cipher, The Data Encryption Standard (DES), DES example.
[1] Chapter 3 (Section 3.3), and Chapter 4 (Sections 4.1 to 4.3)
[2] Chapter 2 (Sections 2.8, and 2.10)

Weeks 5 and 6: Review of basic concepts in Number theory and Finite Fields: Divisibility, Polynomial and modular arithmetic, Statements of Fermat's and Euler's theorems, The Chinese remainder theorem, Discrete logarithm, Finite fields of the form GF(p) and GF(2^n).
[1] Chapter 1 (Sections 2.1 to 2.3, 2.5, 2.7, and 2.8), and Chapter 5 (Sections 5.4 to 5.6)

Weeks 7 and 8: Advanced encryption standard (AES), AES transformation functions, AES key expansion, AES example.
[1] Chapter 6 [Sections 6.1 to 6.5 (up to page 195)]

Weeks 9 and 10: Principles of public-key cryptosystems, The RSA algorithm and security of RSA, Elliptic curve arithmetic, Elliptic curve cryptography.
[1] Chapter 9 (Sections 9.1, and 9.2), and Chapter 10 (Sections 10.3, and 10.4)

Week 11: Cryptographic Hash functions, Secure Hash algorithm.
[1] Chapter 11 (Sections 11.1, and 11.5)

Weeks 12 and 13: Digital signatures, Elgamal and Schnorr digital signature schemes, The digital signature algorithm. Wireless network and mobile device security.
[1] Chapter 13 (Sections 13.1 to 13.4), and Chapter 18 (Sections 18.1, and 18.2)

Week 14: Email architecture, threats and security, Secure/Multipurpose Internet Mail Extension (S/MIME) and Pretty Good Privacy (PGP).
[1] Chapter 19 [Sections 19.1 to 19.5 (Confidentiality excluded)]

Semester-VI

BMATH613: Complex Analysis

Total Marks: 150 (Theory: 75, Internal Assessment: 25 and Practical: 50)
Workload: 4 Lectures, 4 Practicals (per week), **Credits:** 6 (4+2)
Duration: 14 Weeks (56 Hrs. Theory + 56 Hrs. Practical) **Examination:** 3 Hrs.

Course Objectives: This course aims to introduce the basic ideas of analysis for complex functions in complex variables with visualization through relevant practicals. Particular emphasis has been laid on Cauchy's theorems, series expansions and calculation of residues.

Course Learning Outcomes: The completion of the course will enable the students to:

i) Understand the significance of differentiability of complex functions leading to the understanding of Cauchy-Riemann equations.
ii) Evaluate the contour integrals and understand the role of Cauchy-Goursat theorem and the Cauchy integral formula.
iii) Expand some simple functions as their Taylor and Laurent series, classify the nature of singularities, find residues and apply Cauchy Residue theorem to evaluate integrals.

Course Contents:

Unit 1: Analytic Functions and Cauchy-Riemann Equations (Lectures: 16)
Functions of complex variable, Mappings; Mappings by the exponential function, Limits, Theorems on limits, Limits involving the point at infinity, Continuity, Derivatives, Differentiation formulae, Cauchy-Riemann equations, Sufficient conditions for differentiability; Analytic functions and their examples.

Unit 2: Elementary Functions and Integrals (Lectures: 14)
Exponential function, Logarithmic function, Branches and derivatives of logarithms, Trigonometric function, Derivatives of functions, Definite integrals of functions, Contours, Contour integrals and its examples, Upper bounds for moduli of contour integrals,

Unit 3: Cauchy's Theorems and Fundamental Theorem of Algebra (Lectures: 12)
Antiderivatives, Proof of antiderivative theorem, Cauchy-Goursat theorem, Cauchy integral formula; An extension of Cauchy integral formula, Consequences of Cauchy integral formula, Liouville's theorem and the fundamental theorem of algebra.

Unit 4: Series and Residues (Lectures: 14)
Convergence of sequences and series, Taylor series and its examples; Laurent series and its examples, Absolute and uniform convergence of power series, Uniqueness of series representations of power series, Isolated singular points, Residues, Cauchy's residue theorem, residue at infinity; Types of isolated singular points, Residues at poles and its examples.

Reference:

1. Brown, James Ward, & Churchill, Ruel V. (2014). *Complex Variables and Applications* (9th ed.). McGraw-Hill Education. New York.

Additional Readings:

i. Bak, Joseph & Newman, Donald J. (2010). *Complex Analysis* (3rd ed.). Undergraduate Texts in Mathematics, Springer. New York.

ii. Zills, Dennis G., & Shanahan, Patrick D. (2003). *A First Course in Complex Analysis with Applications*. Jones & Bartlett Publishers, Inc.

iii. Mathews, John H., & Howell, Rusell W. (2012). *Complex Analysis for Mathematics and Engineering* (6th ed.). Jones & Bartlett Learning. Narosa, Delhi. Indian Edition. (For practicals: Sample materials of files in the form Mathematica/Maple 2011.zip, www.jblearning.com/catalog/9781449604455/).

Practical /Lab work to be performed in Computer Lab:

Modeling of the following similar problems using Mathematica/Maple/MATLAB/Maxima/ Scilab etc.

1. Make a geometric plot to show that the n^{th} roots of unity are equally spaced points that lie on the unit circle $C_1(0) = \{z : |z| = 1\}$ and form the vertices of a regular polygon with n sides, for n = 4, 5, 6, 7, 8.

2. Find all the solutions of the equation $z^3 = 8i$ and represent these geometrically.

3. Write parametric equations and make a parametric plot for an ellipse centered at the origin with horizontal major axis of 4 units and vertical minor axis of 2 units. Show the effect of rotation of this ellipse by an angle of $\frac{\pi}{6}$ radians and shifting of the centre from (0,0) to (2,1), by making a parametric plot.

4. Show that the image of the open disk $D_1(-1-i) = \{z : |z+1+i| < 1\}$ under the linear transformation $w = f(z) = (3 - 4i)z + 6 + 2i$ is the open disk:
$$D_5(-1 + 3i) = \{w : |w + 1 - 3i| < 5\}.$$

5. Show that the image of the right half plane $\operatorname{Re} z = x > 1$ under the linear transformation $w = (-1 + i)z - 2 + 3i$ is the half plane $v > u + 7$, where $u = \operatorname{Re}(w)$, etc. Plot the map.

6. Show that the image of the right half plane $A = \{z : \operatorname{Re} z \geq \frac{1}{2}\}$ under the mapping

   $w = f(z) = \dfrac{1}{z}$ is the closed disk $\overline{D_1(1)} = \{w : |w - 1| \leq 1\}$ in the w- plane.

7. Make a plot of the vertical lines $x = a$, for $a = -1, -\frac{1}{2}, \frac{1}{2}, 1$ and the horizontal lines $y = b$, for $b = -1, -\frac{1}{2}, \frac{1}{2}, 1$. Find the plot of this grid under the mapping $w = f(z) = \dfrac{1}{z}$.

8. Find a parametrization of the polygonal path $C = C_1 + C_2 + C_3$ from $-1 + i$ to $3 - i$, where C_1 is the line from: $-1 + i$ to -1, C_2 is the line from: -1 to $1 + i$ and C_3 is the line from $1 + i$ to $3 - i$. Make a plot of this path.

9. Plot the line segment 'L' joining the point A = 0 to B = $2 + i\frac{\pi}{4}$ and give an exact calculation of $\int_L e^z dz$.

10. Plot the semicircle 'C' with radius 1 centered at $z = 2$ and evaluate the contour integral $\int_C \frac{1}{z-2} dz$.

11. Show that $\int_{C_1} z dz = \int_{C_2} z dz = 4 + 2i$ where C_1 is the line segment from $-1 - i$ to $3 + i$ and C_2 is the portion of the parabola $x = y^2 + 2y$ joining $-1 - i$ to $3 + i$. Make plots of two contours C_1 and C_2 joining $-1 - i$ to $3 + i$.

12. Use ML inequality to show that $\left| \int_C \frac{1}{z^2+1} dz \right| \le \frac{1}{2\sqrt{5}}$, where C is the straight line segment from 2 to $2 + i$. While solving, represent the distance from the point z to the points i and $-i$, respectively, i.e. $|z - i|$ and $|z + i|$ on the complex plane $\mathbb{C}$.

13. Show that $\int_C \frac{dz}{2z^{1/2}}$, where $z^{1/2}$ is the principal branch of the square root function and C is the line segment joining 4 to $8 + 6i$. Also plot the path of integration.

14. Find and plot three different Laurent series representations for the function

$f(z) = \frac{3}{2+z-z^2}$, involving powers of z.

15. Locate the poles of $f(z) = \frac{1}{5z^4 + 26z^2 + 5}$ and specify their order.

16. Locate the zeros and poles of $g(z) = \frac{\pi \cot(\pi z)}{z^2}$ and determine their order. Also justify that Res(g, 0) = $-\pi^2/3$.

17. Evaluate $\int_{C_1^+(0)} \exp(2/z) dz$, where $C_1^+(0)$ denotes the circle: $\{z: |z|=1\}$ with positive orientation. Similarly evaluate $\int_{C_3^+(0)} \frac{1}{z^4 + z^3 - 2z^2} dz$.

Teaching Plan (Theory of BMATH613: Complex Analysis):

Week 1: Functions of complex variable, Mappings, Mappings by the exponential function.
[1] Chapter 2 (Sections 12 to 14)

Week 2: Limits, Theorems on limits, Limits involving the point at infinity, Continuity.
[1] Chapter 2 (Sections 15 to 18)

Week 3: Derivatives, Differentiation formulae, Cauchy-Riemann equations, Sufficient conditions for Differentiability.
[1] Chapter 2 (Sections 19 to 22)

Week 4: Analytic functions, Examples of analytic functions, Exponential function.
[1] Chapter 2 (Sections 24, and 25), and Chapter 3 (Section 29)

Week 5: Logarithmic function, Branches and Derivatives of Logarithms, Trigonometric functions.
[1] Chapter 3 (Sections 30, 31, and 34)

Week 6: Derivatives of functions, Definite integrals of functions, Contours.
[1] Chapter 4 (Sections 37 to 39)

Week 7: Contour integrals and its examples, upper bounds for moduli of contour integrals.
[1] Chapter 4 (Sections 40, 41, and 43).

Week 8: Antiderivatives, proof of antiderivative theorem.
[1] Chapter 4 (Sections 44, and 45)

Week 9: State Cauchy-Goursat theorem, Cauchy integral formula.
[1] Chapter 4 (Sections 46, and 50)

Week 10: An extension of Cauchy integral formula, Consequences of Cauchy integral formula, Liouville's theorem and the fundamental theorem of algebra.
[1] Chapter 4 (Sections 51 to 53)

Week 11: Convergence of sequences, Convergence of series, Taylor series, proof of Taylor's theorem, Examples.
[1] Chapter 5 (Sections 55 to 59)

Week 12: Laurent series and its examples, Absolute and uniform convergence of power series, uniqueness of series representations of power series.
[1] Chapter 5 (Sections 60, 62, 63, and 66).

Week 13: Isolated singular points, Residues, Cauchy's residue theorem, Residue at infinity. [1]: Chapter 6 (Sections 68 to 71)

Week 14: Types of isolated singular points, Residues at poles and its examples.
[1] Chapter 6 (Sections 72 to 74)

BMATH614: Ring Theory and Linear Algebra-II

Total Marks: 100 (Theory: 75, Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: This course introduces the basic concepts of ring of polynomials and irreducibility tests for polynomials over ring of integers, used in finite fields with applications in Cryptography. This course emphasizes the application of techniques using the adjoint of a linear operator and their properties to least squares approximation and minimal solutions to systems of linear equations.

Courses Learning Outcomes: On completion of this course, the student will be able to:

i) Appreciate the significance of unique factorization in rings and integral domains.
ii) Compute with the characteristic polynomial, eigenvalues, eigenvectors, and eigenspaces, as well as the geometric and the algebraic multiplicities of an eigenvalue and apply the basic diagonalization result.
iii) Compute inner products and determine orthogonality on vector spaces, including Gram-Schmidt orthogonalization to obtain orthonormal basis.

Course Contents:

Unit 1: Polynomial Rings and Unique Factorization Domain (UFD) (Lectures: 25)
Polynomial rings over commutative rings, Division algorithm and consequences, Principal ideal domains, Factorization of polynomials, Reducibility tests, Irreducibility tests, Eisenstein criterion, Unique factorization in Z[x]; Divisibility in integral domains, Irreducibles, Primes, Unique factorization domains, Euclidean domains.

Unit 2: Dual Spaces and Diagonalizable Operators (Lectures: 15)
Dual spaces, Double dual, Dual basis, Transpose of a linear transformation and its matrix in the dual basis, Annihilators; Eigenvalues, Eigenvectors, Eigenspaces and characteristic polynomial of a linear operator; Diagonalizability, Invariant subspaces and Cayley-Hamilton theorem; The minimal polynomial for a linear operator.

Unit 3: Inner Product Spaces (Lectures: 15)
Inner product spaces and norms, Orthonormal basis, Gram-Schmidt orthogonalization process, Orthogonal complements, Bessel's inequality.

Unit 4: Adjoint Operators and Their Properties (Lectures: 15)
The adjoint of a linear operator, Least squares approximation, Minimal solutions to systems of linear equations, Normal, Self-adjoint, Unitary and orthogonal operators and their properties.

References:

1. Friedberg, Stephen H., Insel, Arnold J., & Spence, Lawrence E. (2003). *Linear Algebra* (4th ed.). Prentice-Hall of India Pvt. Ltd. New Delhi.

2. Gallian, Joseph. A. (2013). *Contemporary Abstract Algebra* (8th ed.). Cengage Learning India Private Limited. Delhi. Fourth impression, 2015.

Additional Readings:

i. Herstein, I. N. (2006). *Topics in Algebra* (2nd ed.). Wiley Student Edition. India.
ii. Hoffman, Kenneth, & Kunze, Ray Alden (1978). *Linear Algebra* (2nd ed.). Prentice-Hall of India Pvt. Limited. Delhi. Pearson Education India Reprint, 2015.
iii. Lang, Serge (1987). *Linear Algebra* (3rd ed.). Springer.

Teaching Plan (BMATH614: Ring Theory and Linear Algebra-II):

Week 1: Polynomial rings over commutative rings, Division algorithm and consequences, Principal ideal domains.
[2] Chapter 16

Weeks 2 and 3: Factorization of polynomials, Reducibility tests, Irreducibility tests, Eisenstein's criterion, Unique factorization in Z[x].
[2] Chapter 17

Weeks 4 and 5: Divisibility in integral domains, Irreducibles, Primes, Unique factorization domains, Euclidean domains.
[2] Chapter 18

Week 6: Dual spaces, Double dual, Dual basis, Transpose of a linear transformation and its matrix in the dual basis**,** Annihilators.
[1] Chapter 2 (Section 2.6)

Weeks 7 and 8: Eigenvalues, Eigenvectors, Eigenspaces and characteristic polynomial of a linear operator; Diagonalizability, Invariant subspaces and Cayley-Hamilton theorem; The minimal polynomial for a linear operator.
[1] Chapter 5 (Sections 5.1, 5.2, and 5.4), and Chapter 7 (Section 7.3, Statement of Theorem 7.16)

Week 9: Inner product spaces and norms.
[1] Chapter 6 (Section 6.1)

Weeks 10 and 11: Orthonormal basis, Gram-Schmidt orthogonalization process, Orthogonal complements, Bessel's inequality.
[1] Chapter 6 (Section 6.2)

Week 12: The adjoint of a linear operator and its properties, Least squares approximation, Minimal solutions to systems of linear equations.
[1] Chapter 6 (Section 6.3, Statement of Theorem 6.13 with applications)

Weeks 13 and 14: Normal, Self-adjoint, unitary and orthogonal operators and their properties.
[1] Chapter 6 (Sections 6.4, and 6.5, up to Theorem 6.21, page 385)

Discipline Specific Elective (DSE) Course - 3

Any *one* of the following (at least *two* shall be offered by the college):

DSE-3 (i): Mathematical Finance
DSE-3 (ii): Introduction to Information Theory and Coding
DSE-3 (iii): Biomathematics

DSE-3 (i): Mathematical Finance

Total Marks: 100 (Theory: 75 + Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: This course is an introduction to the application of mathematics in financial world, that enables the student to understand some computational and quantitative techniques required for working in the financial markets and actuarial mathematics.

Course Learning outcomes: In this course, the student will learn the basics of:
i) Financial markets and derivatives including options and futures.
ii) Pricing and hedging of options, interest rate swaps and no-Arbitrage pricing concept.
iii) Stochastic analysis (Ito formula and Ito integration) and the Black-Scholes model.

Course Contents:

Unit 1: Interest Rates (Lectures: 20)
Interest rates, Types of rates, Measuring interest rates, Zero rates, Bond pricing, Forward rate, Duration, Convexity, Exchange traded markets and OTC markets, Derivatives--Forward contracts, Futures contract, Options, Types of traders, Hedging, Speculation, Arbitrage.

Unit 2: Mechanics and Properties of Options (Lectures: 15)
No Arbitrage principle, Short selling, Forward price for an investment asset, Types of Options, Option positions, Underlying assets, Factors affecting option prices, Bounds on option prices, Put-call parity, Early exercise, Effect of dividends.

Unit 3: Stochastic Analysis of Stock Prices and Black-Scholes Model (Lectures: 20)
Binomial option pricing model, Risk neutral valuation (for European and American options on assets following binomial tree model), Lognormal property of stock prices, Distribution of rate of return, expected return, Volatility, estimating volatility from historical data, Extension of risk neutral valuation to assets following GBM, Black-Scholes formula for European options.

Unit 4: Hedging Parameters, Trading Strategies and Swaps (Lectures: 15)
Hedging parameters (the Greeks: Delta, Gamma, Theta, Rho and Vega), Trading strategies involving options, Swaps, Mechanics of interest rate swaps, Comparative advantage argument, Valuation of interest rate swaps, Currency swaps, Valuation of currency swaps.

Reference:

1. Hull, J. C., & Basu, S. (2010). *Options, Futures and Other Derivatives* (7th ed.). Pearson Education. New Delhi.

Additional Readings:

i. Luenberger, David G. (1998). *Investment Science*, Oxford University Press. Delhi.
ii. Ross, Sheldon M. (2011). *An elementary Introduction to Mathematical Finance* (3rd ed.). Cambridge University Press. USA.

Teaching Plan (DSE-3 (i): Mathematical Finance):

Weeks 1 and 2: Interest rates, Types of rates, measuring interest rates, zero rates, Bond pricing, Forward rate, Duration, Convexity.
[1] Chapter 4 (Section 4.1 to 4.4, 4.6, 4.8, and 4.9)

Weeks 3 and 4: Exchange Traded Markets and OTC markets, Derivatives- Forward contracts, Futures contract, Options, Types of traders, Hedging, Speculation, Arbitrage
[1] Chapter 1 (Sections 1.1 to 1.9)

Week 5: No Arbitrage principle, Short selling, Forward price for an investment asset.
[1] Chapter 5 (Sections 5.2 to 5.4)

Week 6: Types of Options, Option positions, Underlying assets, Factors affecting option prices.
[1] Chapter 8 (Sections 8.1 to 8.3), and Chapter 9 (Section 9.1)

Week 7: Bounds on option prices, Put-call parity, Early exercise, Effect of dividends.
[1] Chapter 9 (Sections 9.2 to 9.7)

Week 8: Binomial option pricing model, Risk neutral Valuation (for European and American options on assets following binomial tree model).
[1] Chapter 11 (Sections 11.1 to 11.5)

Weeks 9 to 11: Lognormal property of stock prices, Distribution of rate of return, expected return, Volatility, estimating volatility from historical data. Extension of risk neutral valuation to assets following GBM (without proof), Black-Scholes formula for European options.
[1] Chapter 13 (Sections 13.1 to 13.4, 13.7, and 13.8)

Week 12: Hedging parameters (the Greeks: Delta, Gamma, Theta, Rho and Vega).
[1] Chapter 17 (Sections 17.1 to 17.9)

Week 13: Trading strategies Involving options.
[1] Chapter 10 (except box spreads, calendar spreads and diagonal spreads)

Week 14: Swaps, Mechanics of interest rate swaps, Comparative advantage argument, Valuation of interest rate swaps, Currency swaps, Valuation of currency swaps
[1] Chapter 7 (Sections 7.1 to 7.4, and 7.7 to 7.9)

DSE-3 (ii): Introduction to Information Theory and Coding

Total Marks: 100 (Theory: 75, Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination**: 3 Hrs.

Course Objectives: This course aims to introduce the basic aspects of Information Theory and Coding to the students. Shannon's work form the underlying theme for the present course. Construction of finite fields and bounds on the parameters of a linear code discussed.

Course Learning Outcomes: This course will enable the students to learn:
- i) The output of the channel, a received signal is observed.
- ii) The detection & correction of errors while transmission.
- iii) Representation of a linear code by matrices and its encoding and decoding.

Course Contents:

Unit 1: Concepts of Information Theory (Lectures: 20)
Communication processes, A model of communication system, A quantitative measure of information, Binary unit of information, A measure of uncertainty, H function as a measure of uncertainty, Sources and binary sources, Measure of information for two-dimensional discrete finite probability schemes.

Unit 2: Entropy Function (Lectures: 20)
A sketch of communication network, Entropy, Basic relationship among different entropies, A measure of mutual information, Interpretation of Shannon's fundamental inequalities; Redundancy, Efficiency and channel capacity, Binary symmetric channel, Binary erasure channel, Uniqueness of the entropy function, Joint entropy and conditional entropy, Relative entropy and mutual information, Chain rules for entropy, Conditional relative entropy and conditional mutual information, Jensen's inequality and its characterizations, The log sum inequality and its applications.

Unit 3: Concepts of Coding (Lectures: 15)
Block codes, Hamming distance, Maximum likelihood decoding, Levels of error handling, Error correction, Error detection, Erasure correction, Construction of finite fields, Linear codes, Matrix representation of linear codes.

Unit 4: Bounds of Codes (Lectures: 15)
Orthogonality relation, Encoding of linear codes, Decoding of linear codes, The singleton bound and maximum distance separable codes, The sphere-packing bound and perfect codes, The Gilbert-Varshamov bound, MacWilliams' identities.

References:

1. Cover, Thomas M., & Thomas, Joy A. (2006). *Elements of Information Theory* (2nd ed.). Wiley India. Indian Reprint 2014.
2. Gallian, Joseph. A. (2013). *Contemporary Abstract Algebra* (8th ed.). Cengage Learning India Private Limited. Delhi. Fourth impression, 2015.
3. Reza, Fazlollah M. (1961). *An Introduction to Information Theory*. Dover Publications Inc, New York. Reprint 1994.
4. Roth, Ron M. (2007). *Introduction to Coding Theory*. Cambridge University Press.

Additional Readings:

i. Ash, Robert B. (1965). *Information Theory*. Dover Publications, Inc. New York. Reprint in 1990.
ii. Goldman, Stanford (1968). *Information Theory*, Dover Publications, Inc. New York. Reprint in 1990.
iii. Ling, San & Xing, Chaoping (2004). *Coding Theory*: *A First Course*. Cambridge University Press.

Teaching Plan (DSE-3 (ii): Introduction to Information Theory and Coding):

Weeks 1 and 2: Communication processes, A model of communication system, A quantitative measure of information, Binary unit of information.
[3] Chapter 1 (Sections 1.1 to 1.7)

Weeks 3 and 4: A measure of uncertainty, H function as a measure of uncertainty, Sources and binary sources, Measure of information for two-dimensional discrete finite probability schemes.
[3] Chapter 3 (Sections 3.1 to 3.7)

Weeks 5 and 6: A sketch of communication network, Entropy, Basic relationship among different entropies, A measure of mutual information, Interpretation of Shannon's fundamental inequalities; redundancy, efficiency and channel capacity, Binary symmetric channel, Binary erasure channel, Uniqueness of the entropy function.
[3] Chapter 3 (Sections 3.9, 3.11 to 3.16, and 3.19)
[1] Chapter 2 (Section 2.1)

Weeks 7 and 8: Joint entropy and conditional entropy, Relative entropy and mutual information, Chain rules for entropy, Conditional relative entropy and conditional mutual information, Jensen's inequality and its characterizations, The log sum inequality and its applications.
[1] Chapter 2 (Sections 2.2 to 2.7)

Weeks 9 and 10: Block codes, Hamming distance, Maximum likelihood decoding, Levels of error handling, Error correction, Error detection, Erasure correction, Construction of finite fields.
[4] Chapter 1 (Sections 1.2 to 1.5, excluding 1.5.3), and Chapter 3 (Sections 3.1 to 3.4)

Weeks 11 and 12: Linear codes, Matrix representation of linear codes, Orthogonality relation, Encoding of linear codes, Decoding of linear codes.
[4] Chapter 2 (Sections 2.1 to 2.4)
[2] Chapter 31 (Lemma and Theorem 31.3 on page 538)

Weeks 13 and 14: The singleton bound and maximum distance separable codes, The sphere-packing bound and perfect codes, the Gilbert-Varshamov bound, MacWilliams' identities.
[4] Chapter 4 (Sections 4.1 to 4.4), and Chapter 11 (Section 11.1)

DSE-3 (iii): Biomathematics

Total Marks: 100 (Theory: 75 + Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: The focus of the course is on scientific study of normal functions in living systems. The emphasis is on exposure to nonlinear differential equations with examples such as heartbeat, chemical reactions and nerve impulse transmission. The basic concepts of the probability to understand molecular evolution and genetics have also been applied.

Course Learning outcomes: Apropos conclusion of the course will empower the student to:

i) Learn the development, analysis and interpretation of bio mathematical models.
ii) Reinforce the skills in mathematical modeling.
iii) Appreciate the theory of bifurcation and chaos.
iv) Learn to apply the basic concepts of probability to molecular evolution and genetics.

Course Contents:

Unit 1: Modeling Biological Phenomenon (Lectures: 14)
Population growth, Administration of drugs, Cell division, Systems of linear ordinary differential equations, Heartbeat, Nerve impulse transmission, Chemical reactions, Predator-prey models.

Unit 2: Mathematics of Heart Physiology and Nerve Impulse Transmission (Lectures: 28)
Stability and oscillations**:** Epidemics, The phase plane and the Jacobian matrix, Local stability, Stability, Limit cycles, Forced oscillations; Mathematics of Heart Physiology**:** The local model, The Threshold effect, The phase plane analysis and the heartbeat model, A model of the cardiac pacemaker; Mathematics of Nerve Impulse Transmission**:** Excitability and repetitive firing, Travelling waves.

Unit 3: Bifurcation and Chaos (Lectures: 13)
Bifurcation, Bifurcation of a limit cycle, Discrete bifurcation and period-doubling, Chaos, Stability of limit cycles, The Poincaré plane.

Unit 4: Modeling Molecular Evolution and Genetics (Lectures: 15)
Modelling Molecular Evolution**:** Matrix models of base substitutions for DNA sequences, The Jukes-Cantor model, The Kimura models, Phylogenetic distances; Constructing Phylogenetic Trees**:** Phylogenetic trees, Unweighted pair-group method with arithmetic means (UPGMA), Neighbor joining method; Genetics**:** Mendelian genetics, Probability distributions in genetics.

References:

1. Allman, Elizabeth S., & Rhodes, John A. (2004). *Mathematical Models in Biology*: *An Introduction*. Cambridge University Press.
2. Jones, D. S., Plank, M. J., & Sleeman, B. D. (2009). *Differential Equations and Mathematical Biology* (2nd ed.). CRC Press, Taylor & Francis Group, LLC.

Additional Readings:

i. Murray, J. D. (2002). *An Introduction to Mathematical Biology* (3rd ed.). Springer.
ii. Myint-U, Tyn (1977). *Ordinary Differential Equations*. Elsevier North-Holland, Inc.
iii. Simmons, George F., & Krantz, Steven G. (2015). *Differential Equations*. McGraw-Hill Education. Indian Reprint.
iv. Strogatz, Steven H. (2009). *Nonlinear Dynamics and Chaos* (2nd ed.). Perseus Book Publishing. LLC. Sarat Publication, Kolkata, India.

Teaching Plan (DSE-3 (iii): Biomathematics):

Week 1: Population growth, Administration of drugs, Cell division, Systems of linear ordinary differential equations.
[2] Chapter 1 (Sections 1.1 to 1.3), and Chapter 3 (An overview of the methods in Sections 3.1 to 3.6)

Week 2: Heartbeat, Nerve impulse transmission
[2] Chapter 4 (Sections 4.2, and 4.3)

Week 3: Chemical reactions, Predator-prey models, Epidemics (Mathematical model).
[2] Chapter 4 (Sections 4.4, and 4.5), and Chapter 5 (Section 5.2)

Week 4: The phase plane and Jacobian matrix, Local stability.
[2] Chapter 5 (Sections 5.3, and 5.4)

Week 5: Stability, Limit cycles.
[2] Chapter 5 [Sections 5.5, and 5.6 (up to page number 137)]

Week 6: Limit cycle criterion and Poincaré-Bendixson Theorem (interpretation only, with Example 5.6.1), Forced oscillations.
[2] Chapter 5 [Section 5.6 (Page number 137 to 138), and Section 5.7)

Week 7: Mathematics of Heart Physiology: The local model, The Threshold effect, The phase plane analysis and the heartbeat model.
[2] Chapter 6 (Sections 6.1 to 6.3)

Week 8: A model of the cardiac pacemaker, Excitability and repetitive firing.
[2] Chapter 6 (Section 6.5), and Chapter 7 (Section 7.1)

Week 9: Travelling waves, Bifurcation, Bifurcation of a limit cycle.
[2] Chapter 7 (Section 7.2), and Chapter 13 (Sections 13.1, and 13.2)

Weeks 10 and 11: Discrete bifurcation and period-doubling, Chaos, Stability of limit cycles, The Poincaré plane.
[2] Chapter 13 (Sections 13.3 to 13.6)

Week 12: Matrix models of base substitutions for DNA sequences, The Jukes-Cantor model, The Kimura models, Phylogenetic distances.
[1] Chapter 4 (Sections 4.4, and 4.5)

Week 13: Constructing Phylogenetic Trees: Phylogenetic trees, Unweighted pair-group method with arithmetic means (UPGMA), Neighbor joining method.
[1] Chapter 5 (Sections 5.1 to 5.3)

Week 14: Genetics**:** Mendelian Genetics, Probability distributions in Genetics.
[1] Chapter 6 [Sections 6.1, and 6.2 (up to Equation 6.2 only)]

Discipline Specific Elective (DSE) Course - 4

Any *one* of the following (at least *two* shall be offered by the college):

DSE-4 (i): Number Theory
DSE-4 (ii): Linear Programming and Applications
DSE-4 (iii): Mechanics

DSE-4 (i): Number Theory

Total Marks: 100 (Theory: 75 and Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: In number theory there are challenging open problems which are comprehensible at undergraduate level, this course is intended to build a micro aptitude of understanding aesthetic aspect of mathematical instructions and gear young minds to ponder upon such problems. Also, another objective is to make the students familiar with simple number theoretic techniques, to be used in data security.

Course Learning Outcomes: This course will enable the students to learn:

i) Some of the open problems related to prime numbers, viz., Goldbach conjecture etc.
ii) About number theoretic functions and modular arithmetic.
iii) Public crypto systems, in particular, RSA.

Course Contents:

Unit 1: Distribution of Primes and Theory of Congruencies (Lectures: 15)
Linear Diophantine equation, Prime counting function, Prime number theorem, Goldbach conjecture, Fermat and Mersenne primes, Congruence relation and its properties, Linear congruence and Chinese remainder theorem, Fermat's little theorem, Wilson's theorem.

Unit 2: Number Theoretic Functions (Lectures: 15)
Number theoretic functions for sum and number of divisors, Multiplicative function, The Mobius inversion formula, The greatest integer function. Euler’s phi-function and properties, Euler’s theorem.

Unit 3: Primitive Roots (Lectures: 20)
The order of an integer modulo *n*, Primitive roots for primes, Composite numbers having primitive roots; Definition of quadratic residue of an odd prime, and Euler’s criterion.

Unit 4: Quadratic Reciprocity Law and Public Key Encryption (Lectures: 20)
The Legendre symbol and its properties, Quadratic reciprocity, Quadratic congruencies with composite moduli; Public key encryption, RSA encryption and decryption.

References:

1. Burton, David M. (2012). *Elementary Number Theory* (7th ed.). Mc-Graw Hill Education Pvt. Ltd. Indian Reprint.
2. Jones, G. A., & Jones, J. Mary. (2005). *Elementary Number Theo*ry. Undergraduate Mathematics Series (SUMS). First Indian Print.

Additional Reading:

i. Neville Robinns. (2007). *Beginning Number Theory* (2nd ed.). Narosa Publishing House Pvt. Limited, Delhi.

Teaching Plan (DSE-4 (i): Number Theory):

Week 1: Linear Diophantine equation and its solutions, Distribution of primes, Prime counting function, Statement of the prime number theorem, Goldbach conjecture.
[1] Chapter 2 (Section 2.5)
[2] Chapter 2 (Section 2.2)

Week 2: Fermat and Mersenne primes, Congruence relation and its basic properties, Linear congruence equation and its solutions.
[2] Chapter 2 (Section 2.3)
[1] Chapter 4 (Sections 4.2, and 4.4)

Week 3: Chinese remainder theorem, to solve system of linear congruence for two variables, Fermat's little theorem, Wilson's theorem.
[1] Chapter 4 (Section 4.4), Chapter 5 (Section 5.2 up to before pseudo-prime at page 90, Section 5.3)

Weeks 4 and 5: Number theoretic functions for sum and number of divisors, Multiplicative function, and the Mobius inversion formula. The greatest integer function, Euler's phi-function.
[1] Chapter 6 (Sections 6.1 to 6.2), and Chapter 7 (Section 7.2)

Week 6: Euler's theorem, Properties of Euler’s phi-function.
[1] Chapter 7 (Sections 7.3, and 7.4)

Weeks 7 and 8: The order of an integer modulo *n*. Primitive roots for primes.
[1] Chapter 8 (Sections 8.1, and 8.2)

Week 9: Composite numbers having primitive roots.
[1] Chapter 8 (Section 8.3)

Week 10: Definition of quadratic residue of an odd prime, and Euler's criterion.
[1] Chapter 9 (Section 9.1)

Weeks 11 and 12: The Legendre symbol and its properties. Quadratic reciprocity law.
[1] Chapter 9 (Section 9.2 up to page 181, and Section 9.3)

Week 13: Quadratic congruencies with composite moduli.
[1] Chapter 9 (Section 9.4)

Week 14: Public key encryption, RSA encryption and decryption scheme.
[1] Chapter 10 (Section 10.1)

DSE-4 (ii): Linear Programming and Applications

Total Marks: 100 (Theory: 75 and Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination:** 3 Hrs.

Course Objectives: This course develops the ideas underlying the Simplex Method for Linear Programming Problem, as an important branch of Operations Research. The course covers Linear Programming with applications to Transportation, Assignment and Game Problem. Such problems arise in manufacturing resource planning and financial sectors.

Course Learning Outcomes: This course will enable the students to learn:

i) Analyze and solve linear programming models of real life situations.
ii) The graphical solution of LPP with only two variables, and illustrate the concept of convex set and extreme points. The theory of the simplex method is developed.
iii) The relationships between the primal and dual problems and their solutions with applications to transportation, assignment and two-person zero-sum game problem.

Course Contents:

Unit 1: Introduction to Linear Programming (Lectures: 15)
The Linear Programming Problem**:** Standard, Canonical and matrix forms, Graphical solution. Hyperplanes, Extreme points, Convex and polyhedral sets. Basic solutions; Basic Feasible Solutions; Reduction of any feasible solution to a basic feasible solution; Correspondence between basic feasible solutions and extreme points.

Unit 2: Methods of Solving Linear Programming Problem (Lectures: 25)
Simplex Method**:** Optimal solution, Termination criteria for optimal solution of the Linear Programming Problem, Unique and alternate optimal solutions, Unboundedness; Simplex Algorithm and its Tableau Format; Artificial variables, Two-phase method, Big-M method.

Unit 3: Duality Theory of Linear Programming (Lectures: 15)
Motivation and Formulation of Dual problem; Primal-Dual relationships; Fundamental Theorem of Duality; Complimentary Slackness.

Unit 4: Applications (Lectures: 15)
*Transportation Problem***:** Definition and formulation; Methods of finding initial basic feasible solutions; North West corner rule. Least cost method; Vogel's Approximation method; Algorithm for solving Transportation Problem.
*Assignment Problem***:** Mathematical formulation and Hungarian method of solving.
*Game Theory***:** Basic concept, Formulation and solution of two-person zero-sum games, Games with mixed strategies, Linear Programming method of solving a game.

References:

1. Bazaraa, Mokhtar S., Jarvis, John J., & Sherali, Hanif D. (2010). *Linear Programming and Network Flows* (4th ed.). John Wiley and Sons.
2. Hadley, G. (1997). *Linear Programming*. Narosa Publishing House. New Delhi.

3. Taha, Hamdy A. (2010). *Operations Research*: *An Introduction* (9th ed.). Pearson.

Additional Readings:

i. Hillier, Frederick S. & Lieberman, Gerald J. (2015). *Introduction to Operations Research* (10th ed.). McGraw-Hill Education (India) Pvt. Ltd.
ii. Thie, Paul R., & Keough, G. E. (2014). *An Introduction to Linear Programming and Game Theory*. (3rd ed.). Wiley India Pvt. Ltd.

Teaching Plan (DSE-4 (ii): Linear Programming and Applications):

Week 1: The Linear Programming Problem: Standard, Canonical and matrix forms, Graphical solution.
[1] Chapter 1 (Section 1.1)
[2] Chapter 1 (Sections 1.1 to 1.4, and 1.6)

Weeks 2 and 3: Hyperplanes, Extreme points, Convex and polyhedral sets; Basic solutions. Basic Feasible Solutions; Reduction of any feasible solution to a basic feasible solution; Correspondence between basic feasible solutions and extreme points.
[2] Chapter 2 (Sections 2.16, 2.19, and 2.20), and Chapter 3 (Sections 3.4, and 3.10)
[1] Chapter 3 (Section 3.2)

Week 4: Simplex Method: Optimal solution, Termination criteria for optimal solution of the Linear Programming Problem, Unique and alternate optimal solutions, Unboundedness.
[1] Chapter 3 (Sections 3.3, and 3.6)

Weeks 5 and 6: Simplex Algorithm and its Tableau Format.
[1] Chapter 3 (Sections 3.7, and 3.8).

Weeks 7 and 8: Artificial variables, Two-phase method, Big-M method.
[1] Chapter 4 (Sections 4.1 to 4.3)

Weeks 9 and 10: Motivation and Formulation of Dual problem; Primal-Dual relationships.
[1] Chapter 6 (Section 6.1, and 6.2, up to Example 6.4)

Week 11: Statements of the Fundamental Theorem of Duality and Complimentary Slackness Theorem with examples.
[1] Chapter 6 (Section 6.2)

Weeks 12 and 13: Transportation Problem. Assignment problem.
[3] Chapter 5 (Sections 5.1, 5.3, and 5.4)

Week 14: *Game Theory***:** Basic concept, Formulation and solution of two-person zero-sum games, Games with mixed strategies, Linear Programming method of solving a game.
[2] Chapter 11 (Sections 11.12, and 11.13)

DSE-4 (iii): Mechanics

Total Marks: 100 (Theory: 75, Internal Assessment: 25)
Workload: 5 Lectures, 1 Tutorial (per week) **Credits:** 6 (5+1)
Duration: 14 Weeks (70 Hrs.) **Examination**: 3 Hrs.

Course Objectives: The course aims at understanding the various concepts of physical quantities and the related effects on different bodies using mathematical techniques. It emphasizes knowledge building for applying mathematics in physical world.

Course Learning Outcomes: The course will enable the students to understand:
i) The significance of mathematics involved in physical quantities and their uses;
ii) To study and to learn the cause-effect related to these; and
iii) The applications in observing and relating real situations/structures.

Course Contents:

Unit 1: Forces in Equilibrium (Lectures: 20)
Coplanar force systems; Three-dimensional force systems; Moment of a force about a point and an axis, Principle of moments, Couple and couple moment, Moment of a couple about a line, Resultant of a force system, Distributed force system, Rigid-body equilibrium, Equilibrium of forces in two and three dimensions, Free-body diagrams, General equations of equilibrium, Constraints and statical determinacy.

Unit 2: Friction, Center of Gravity and Moments of Inertia (Lectures: 20)
Equations of equilibrium and friction, Frictional forces on screws and flat belts; Center of gravity, Center of mass and Centroid of a body and composite bodies; Theorems of Pappus and Guldinus; Moments and products of inertia for areas, composite areas and rigid body, Parallel-axis theorem, Moment of inertia of a rigid body about an arbitrary axis, Principal moments and principal axes of inertia.

Unit 3: Conservation of Energy and Applications (Lectures: 15)
Conservative force fields, Conservation of mechanical energy, Work-energy equations, Kinetic energy and work-kinetic energy expressions based on center of mass, Moment of momentum equation for a single particle and a system of particles.

Unit 4: Rigid Body Motion (Lectures: 15)
Translation and rotation of rigid bodies, Chasles' Theorem, General relationship between time derivatives of a vector for different references, Relationship between velocities of a particle for different references, Acceleration of particle for different references.

References:

1. Hibbeler, R. C. (2016). *Engineering Mechanics*: *Statics & Dynamics* (14th ed.). Pearson Prentice Hall (Pearson Education), New Jersey.
2. Shames, Irving H., & Rao, G. Krishna Mohan (2009). *Engineering Mechanics*: *Statics and Dynamics* (4th ed.). Dorling Kindersley (India) Pvt. Ltd. (Pearson Education). Delhi.

Additional Reading:

i. Nelson, E. W., Best, Charles L. & McLean, W. G. (1998). *Theory and Problems of Engineering Mechanics*: *Statics and Dynamics* (5th ed.). McGraw-Hill, Schaum's Outline Series.

Teaching Plan (DSE-4 (iii): Mechanics):

Weeks 1 and 2: Coplanar force systems; Three-dimensional force systems. Moment of a force about a point and an axis, Principle of moments, Couple and couple moment, Moment of a couple about a line, Resultant of a force system, Distributed force system.
[1] Chapter 3, and Chapter 4

Weeks 3 and 4: Rigid-body equilibrium, Equilibrium of forces in two and three dimensions, Free-body diagrams, General equations of equilibrium, Constraints and statical determinacy.
[1] Chapter 5

Weeks 5 and 6: Equations of equilibrium and friction, Frictional forces on screws and flat belts; Center of gravity, Center of mass and Centroid of a body and composite bodies; Theorems of Pappus and Guldinus.
[1] Chapter 8, and Chapter 9

Weeks 7 and 8: Moments and products of inertia for areas, composite areas and rigid body, Parallel-axis theorem, Moment of inertia of a rigid body about an arbitrary axis, Principal moments and principal axes of inertia.
[1] Chapter 10 (Sections 10.1 to 10.5), and Chapter 21 (Section 21.1)

Weeks 9 to 11: Conservative force fields, Conservation of mechanical energy, Work-energy equations, Kinetic energy and work-kinetic energy expressions based on center of mass, Moment of momentum equation for a single particle and a system of particles.
[2] Chapter 11, and Chapter 12 (Sections 12.5, and 12.6)

Weeks 12 to 14: Translation and rotation of rigid bodies, Chasles' Theorem, General relationship between time derivatives of a vector for different references, Relationship between velocities of a particle for different references, Acceleration of particle for different references.
[2] Chapter 13 (Sections 13.1 to 13.3, and 13.6 to 13.8)

UNIVERSITY OF DELHI

CNC-II/093/1(25)/2023-24/64
Dated: 30.05.2023

N O T I F I C A T I O N

Sub: Amendment to Ordinance V

[E.C Resolution No. 60/ (60-1-7/) dated 03.02.2023]

Following addition be made to Appendix-II-A to the Ordinance V (2-A) of the Ordinances of the University;

Add the following:

Syllabi of Semester-III of the following departments under Faculty of Mathematical Sciences based on Under Graduate Curriculum Framework -2022 implemented from the Academic Year 2022-23.

FACULTY OF MATHEMATICAL SCIENCES

DEPARTMENT OF COMPUTER SCIENCE

BSC. (HONS.) COMPUTER SCIENCE

DISCIPLINE SPECIFIC CORE COURSE -7 (DSC-7) : Data Structures

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC07 Data Structures	4	3	0	1	Passed 12th class with Mathematics	Programming using Python/Object Oriented Programming with C++

Learning Objectives

The course aims at developing the ability to use basic data structures like arrays, stacks, queues, lists, and trees to solve problems. C++ is chosen as the language to implement the implementation of these data structures.

Learning outcomes

On successful completion of the course, students will be able to:

- Compare two functions for their rates of growth.
- Understand abstract specification of data-structures and their implementation.
- Compute time and space complexity of operations on a data-structure.
- Identify the appropriate data structure(s) for a given application and understand the trade-offs involved in terms of time and space complexity.
- Apply recursive techniques to solve problems.

SYLLABUS OF DSC-7

Unit 1 (9 hours)

Growth of Functions, Recurrence Relations: Functions used in analysis, asymptotic notations, asymptotic analysis, solving recurrences using recursion trees, Master Theorem.

Unit 2 (16 hours)

Arrays, Linked Lists, Stacks, Queues: Arrays: array operations, applications, two-dimensional arrays, dynamic allocation of arrays; Linked Lists: singly linked lists, doubly linked lists, circularly linked lists, Stacks: stack as an ADT, implementing stacks using arrays, implementing stacks using linked lists, applications of stacks; Queues: queue as an ADT, implementing queues using arrays, implementing queues using linked lists,. Time complexity analysis.

Unit 3 (5 hours)

Recursion: Recursive functions, linear recursion, binary recursion.

Unit 4 (6 hours)

Trees, Binary Trees: Trees: definition and properties, tree traversal algorithms, and their time complexity analysis; binary trees: definition and properties, traversal of binary trees, and their time complexity analysis.

Unit 5 (7 hours)

Binary Search Trees, Balanced Search Trees: Binary Search Trees: insert, delete, search operations, time complexity analysis of these operations; Balanced Search Trees: insert, search operations, time complexity analysis of these operations. Time complexity analysis.

Unit 6 (2 hours)

Binary Heap: Binary Heaps: heaps, heap operations.

Essential/recommended readings

1. Goodrich, M.T., Tamassia, R., & Mount, D., *Data Structures and Algorithms Analysis in C++,* 2nd edition, Wiley, 2011.
2. Cormen, T.H., Leiserson, C.E., Rivest, R. L., Stein C. *Introduction to Algorithms*, 4th edition, Prentice Hall of India, 2022.

Additional references

1. Sahni, S. *Data Structures, Algorithms and applications in C++*, 2nd edition, Universities Press, 2011.
2. Langsam Y., Augenstein, M. J., & Tanenbaum, A. M. *Data Structures Using C and C++*, Pearson, 2009.

Practical List (If any): (30 Hours)

Practical exercises such as

1. Write a program to implement singly linked list as an ADT that supports the following operations:
   (i) Insert an element x at the beginning of the singly linked list
   (ii) Insert an element x at i^{th} position in the singly linked list
   (iii) Remove an element from the beginning of the singly linked list
   (iv) Remove an element from i^{th} position in the singly link
   (v) Search for an element x in the singly linked list and return its pointer
   (vi) Concatenate two singly linked lists

2. Write a program to implement doubly linked list as an ADT that supports the following operations:
   (i) Insert an element x at the beginning of the doubly linked list
   (ii) Insert an element x at i^{th} position in the doubly linked list
   (iii) Insert an element x at the end of the doubly linked list
   (iv) Remove an element from the beginning of the doubly linked list
   (v) Remove an element from i^{th} position in the doubly linked list.
   (vi) Remove an element from the end of the doubly linked list
   (vii) Search for an element x in the doubly linked list and return its pointer
   (viii) Concatenate two doubly linked lists

3. Write a program to implement circular linked list as an ADT which supports the following operations:
   (i) Insert an element x at the front of the circularly linked list
   (ii) Insert an element x after an element y in the circularly linked list
   (iii) Insert an element x at the back of the circularly linked list
   (iv) Remove an element from the back of the circularly linked list
   (v) Remove an element from the front of the circularly linked list
   (vi) Remove the element x from the circularly linked list
   (vii) Search for an element x in the circularly linked list and return its pointer

(viii) Concatenate two circularly linked lists

4. Implement a stack as an ADT using Arrays.

5. Implement a stack as an ADT using the Linked List ADT.

6. Write a program to evaluate a prefix/postfix expression using stacks.

7. Implement Queue as an ADT using the circular Arrays.

8. Implement Queue as an ADT using the Circular Linked List ADT.

9. Write a program to implement Binary Search Tree as an ADT which supports the following operations:
   (i) Insert an element x
   (ii) Delete an element x
   (iii) Search for an element x in the BST and change its value to y and then place the node with value y at its appropriate position in the BST
   (iv) Display the elements of the BST in preorder, inorder, and postorder traversal
   (v) Display the elements of the BST in level-by-level traversal
   (vi) Display the height of the BST

10. Write a program to implement a balanced search tree as an ADT.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE – 8 (DSC-8): Operating Systems

Credit distribution, Eligibility and Prerequisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC 08 Operating Systems	4	3	0	1	Passed 12th class with Mathematics	Programming using Python/Object Oriented Programming with C++, Computer System Architecture

Learning Objectives

The course provides concepts that underlie all operating systems and are not tied to any particular operating system. The emphasis is on explaining the need and structure of an operating system using its common services such as process management (creation, termination etc.), CPU Scheduling, Process Synchronization, Handling Deadlocks, main memory management, virtual memory, secondary memory management. The course also introduces various scheduling algorithms, structures, and techniques used by operating systems to provide these services.

Learning outcomes

On successful completion of the course, students will be able to:

- Describe the need of an operating system and define multiprogramming and Multithreading concepts.
- Implement the process synchronization service (Critical Section, Semaphores), CPU scheduling service with various algorithms.
- Implement Main memory Management (Paging, Segmentation) algorithms, Handling of Deadlocks
- Identify and appreciate the File systems Services, Disk Scheduling service

SYLLABUS OF DSC-8

Unit 1 (6 hours)

Introduction: Operating Systems (OS) definition and its purpose, Multiprogrammed and Time Sharing Systems, OS Structure, OS Operations: Dual and Multi-mode, OS as resource manager.

Unit 2 (9 hours)

Operating System Structures: OS Services, System Calls: Process Control, File Management, Device Management, and Information Maintenance, Inter-process Communication, and Protection, System programs, OS structure- Simple, Layered, Microkernel, and Modular.

Unit 3 (10 hours)

Process Management: Process Concept, States, Process Control Block, Process Scheduling, Schedulers, Context Switch, Operation on processes, Threads, Multicore Programming, Multithreading Models, PThreads, Process Scheduling Algorithms: First Come First Served, Shortest-Job-First, Priority & Round-Robin, Process Synchronization: The critical-section problem and Peterson's Solution, Deadlock characterization, Deadlock handling.

Unit 4 (11 hours)

Memory Management: Physical and Logical address space, Swapping, Contiguous memory allocation strategies - fixed and variable partitions, Segmentation, Paging.
Virtual Memory Management: Demand Paging and Page Replacement algorithms: FIFO Page Replacement, Optimal Page replacement, LRU page replacement.

Unit 5 (9 hours)

File System: File Concepts, File Attributes, File Access Methods, Directory Structure: Single-Level, Two-Level, Tree-Structured, and Acyclic-Graph Directories.
Mass Storage Structure: Magnetic Disks, Solid-State Disks, Magnetic Tapes, Disk Scheduling algorithms: FCFS, SSTF, SCAN, C-SCAN, LOOK, and C-LOOk Scheduling.

Essential/recommended readings

1. Silberschatz, A., Galvin, P. B., Gagne G. *Operating System Concepts,* 9th edition, John Wiley Publications, 2016.
2. Tanenbaum, A. S. *Modern Operating Systems*, 3rd edition, Pearson Education, 2007.
3. Stallings, W. *Operating Systems: Internals and Design Principles,* 9th edition, Pearson Education, 2018.

Additional References

1. Dhamdhere, D. M., *Operating Systems: A Concept-based Approach,* 2nd edition, Tata McGraw-Hill Education, 2017.
2. Kernighan, B. W., Rob Pike, R. *The Unix Programming Environment*, Englewood Cliffs, NJ: Prentice-Hall, 1984.

Suggested Practical List (If any): (30 Hours)

Practical exercises such as

1. Execute various Linux commands for:
   i. Information Maintenance: wc, clear, cal, who, date, pwd
   ii. File Management: cat, cp, rm, mv, cmp, comm, diff, find, grep, awk
   iii. Directory Management : cd, mkdir, rmdir, ls
2. Execute various Linux commands for:
   i. Process Control: fork, getpid, ps, kill, sleep
   ii. Communication: Input-output redirection, Pipe
   iii. Protection Management: chmod, chown, chgrp
3. Write a programme (using fork() and/or exec() commands) where parent and child execute:
   i. same program, same code.
   ii. same program, different code.
   iii. Before terminating, the parent waits for the child to finish its task.
4. Write a program to to report behaviour of Linux kernel including kernel version, CPU type and model. (CPU information)

5. Write a program to report behaviour of Linux kernel including information on 19 configured memory, amount of free and used memory. (Memory information)
6. Write a program to copy files using system calls.
7. Use an operating system simulator to simulate operating system tasks.
8. Write a program to implement scheduling algorithms FCFS/ SJF/ SRTF/ non-preemptive scheduling algorithms.
9. Write a program to calculate the sum of n numbers using Pthreads. A list of n numbers is divided into two smaller lists of equal size, and two separate threads are used to sum the sublists.
10. Write a program to implement first-fit, best-fit and worst-fit allocation strategies.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE– 9 (DSC-9): Numerical Optimization

Credit distribution, Eligibility and Pre-requisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC09 Numerical Optimization	**4**	**3**	**0**	**1**	**Passed 12th class with Mathematics**	Programming using Python/Object Oriented Programming with C++

Learning Objectives

The course aims to provide students with the experience of mathematically formulating a large variety of optimization/decision problems emerging out of various fields like data science, machine learning, business, and finance. The course focuses on learning techniques to optimize problems in order to obtain the best possible solution.

Learning outcomes

At the end of the course, students will be able to:

- Mathematically formulate the optimization problems using the required number of independent variables.
- Define constraint functions on a problem.
- Check the feasibility and optimality of a solution.
- Apply conjugate gradient method to solve the problem.

SYLLABUS OF DSC-9

Unit 1 (6 hours)

Introduction: Mathematical Formulation using example, Continuous versus Discrete Optimization, Constrained and Unconstrained Optimization, Global and Local Optimization, Stochastic and Deterministic Optimization, Convexity, Optimization Algorithms

Unit 2 (14 hours)

Fundamentals of Unconstrained Optimization: Concept of a Solution - Recognizing a Local Minimum, Nonsmooth Problems, Overview of Algorithms - Two Strategies: Line Search and Trust Region, Search Directions for Line Search Methods, Models for Trust-Region Methods, Scaling. Line Search - Convergence of Line Search Methods, Rate of Convergence - Convergence Rate of Steepest Descent; Newton's Method, Quasi-Newton Methods. Trust Region - The Cauchy Point Algorithm; Global Convergence - Reduction Obtained by the Cauchy Point; Convergence to Stationary Points.

Unit 3 (7 hours)

Conjugate Gradient Methods: Basic Properties of the Conjugate Gradient Method, A Practical Form of the Conjugate Gradient Method, and Rate of Convergence

Unit 4 (8 hours)

Calculating Derivatives: Finite-Difference Derivative Approximations, Approximating the Gradient, Approximating a Sparse Jacobian, Approximating the Hessian, Approximating a Sparse Hessian

Unit 5 (10 hours)

Theory of Constrained Optimization: Local and Global Solutions, Smoothness, Examples - A Single Equality Constraint, A Single Inequality Constraint, Two Inequality Constraints, Tangent Cone and Constraint Qualifications, First-Order Optimality Condition, Second-Order Conditions - Second-Order Conditions and Projected Hessians. Linear and non-linear constrained optimization, augmented Lagrangian Method

Essential/recommended readings

1. J. Nocedal and S.J. Wright, *Numerical Optimization*, 2nd edition, Springer Series in Operations Research, 2006.
2. A, Mehra, S Chandra, Jayadeva, *Numerical Optimization with Applications*, Narosa Publishing House, New Delhi, 2009,

Additional References

1. R. W. Hamming, *Numerical Methods for Scientists and Engineers,* 2nd edition, Dover Publications, 1986.
2. Q. Kong, T. Siauw, A. Bayen, *Python Programming and Numerical Methods: A Guide for Engineers and Scientists,* 1st edition, 2020.

Suggested Practical List (If any) :(30 Hours)

Practical exercises such as

Write a program to implement the following methods:

Constrained and Unconstrained Optimization, Global and Local Optimization, Line Search and Trust Region, Convergence of Line Search Methods, Rate of Convergence - Convergence Rate of Steepest Descent, Newton's Method, Quasi-Newton Methods, The Cauchy Point algorithm, Finite-Difference Derivative Approximations, Convergence to Stationary Points, Conjugate Gradient Method, Rate of Convergence, Approximating a Sparse Jacobian, Approximating the Hessian, Approximating a Sparse Hessian, First-Order Optimality Condition, Second-Order Conditions - Second-Order Conditions, and Projected Hessians. Linear and non-linear constrained optimization Augmented Lagrangian Methods.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

Computer Science Courses for Undergraduate Programme of study with Computer Science discipline Elective

DISCIPLINE SPECIFIC ELECTIVE COURSE: Data Analysis and Visualization

Credit distribution, Eligibility and Pre-requisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Data Analysis and Visualization (DAV)	**4**	**3**	**0**	**1**	**Pass in XII class**	Programming using Python/ Class XI-XII Computer Science/ Class XI-XII Informatics Practices

Learning Objectives

This course is designed to introduce the students to real-world data analysis problems, the use of statistics to get a deterministic view of data, and interpreting results in the field of exploratory data science using Python. This course is the first in the "Data Science" pathway and builds the foundation for three subsequent courses in the pathway.

Learning outcomes

On successful completion of the course, students will be able to:

1. Apply descriptive statistics to obtain a deterministic view of data
2. Perform data handling using Numpy arrays
3. Load, clean, transform, merge, and reshape data using Pandas
4. Visualize data using Pandas and matplot libraries
5. Solve real world data analysis problems

SYLLABUS OF DSE

Unit 1 (10 hours)

Introduction to basic statistics and analysis: Fundamentals of Data Analysis, Statistical foundations for Data Analysis, Types of data, Descriptive Statistics, Correlation and covariance, Linear Regression, Statistical Hypothesis Generation and Testing, Python Libraries: NumPy, Pandas, Matplotlib

Unit 2 (8 hours)

Array manipulation using Numpy: Numpy array: Creating Numpy arrays; various data types of Numpy arrays, indexing and slicing, swapping axes, transposing arrays, data processing using Numpy arrays.

Unit 3 (12 hours)

Data Manipulation using Pandas: Data Structures in Pandas: Series, DataFrame, Index objects, Loading data into Pandas data frame, Working with DataFrames: Arithmetics, Statistics, Binning, Indexing, Reindexing, Filtering, Handling missing data, Hierarchical indexing, Data wrangling: Data cleaning, transforming, merging and reshaping

Unit 4 (8 hours)

Plotting and Visualization: Using Matplotlib to plot data: figures, subplots, markings, color and line styles, labels and legends, Plotting functions in Pandas: Line, bar, Scatter plots, histograms, stacked bars, Heatmap

Unit 5 (7 hours)

Data Aggregation and Group operations: Group by mechanics, Data aggregation, General split-apply-combine, Pivot tables and cross tabulation

Essential/recommended readings

1. McKinney W. *Python for Data Analysis: Data Wrangling with Pandas, NumPy and IPython*, 2nd edition, O'Reilly Media, 2018.
2. Molin S. *Hands-On Data Analysis with Pandas*, Packt Publishing, 2019.
3. Gupta S.C., Kapoor V.K. *Fundamentals of Mathematical Statistics*,12th edition, Sultan Chand & Sons, 2020.

Additional References

1. Chen D. Y. *Pandas for Everyone: Python Data Analysis*, First edition, Pearson Education, 2018.
2. Miller J.D. *Statistics for Data Science,* Packt Publishing Limited, 2017.

Suggested Practical List (If any): (30 Hours)

Practical exercises such as

Use a dataset of your choice from Open Data Portal (https:// data.gov.in/, UCI repository) or load from scikit, seaborn library for the following exercises to practice the concepts learnt.

1. Load a Pandas dataframe with a selected dataset. Identify and count the missing values in a dataframe. Clean the data after removing noise as follows
   a) Drop duplicate rows.
   b) Detect the outliers and remove the rows having outliers
   c) Identify the most correlated positively correlated attributes and negatively correlated attributes

2. Import iris data using sklearn library or (Download IRIS data from: https://archive.ics.uci.edu/ml/datasets/iris or import it from sklearn.datasets)
   i. Compute mean, mode, median, standard deviation, confidence interval and standard error for each feature
   ii. Compute correlation coefficients between each pair of features and plot heatmap
   iii. Find covariance between length of sepal and petal
   iv. Build contingency table for class feature

3. Load Titanic data from sklearn library , plot the following with proper legend and axis labels:

   a. Plot bar chart to show the frequency of survivors and non-survivors for male and female passengers separately
   b. Draw a scatter plot for any two selected features
   c. Compare density distribution for features age and passenger fare
   d. Use a pair plot to show pairwise bivariate distribution

4. Using Titanic dataset, do the following
   a. Find total number of passengers with age less than 30
   b. Find total fare paid by passengers of first class
   c. Compare number of survivors of each passenger class

5. Download any dataset and do the following
   a. Count number of categorical and numeric features
   b. Remove one correlated attribute (if any)
   c. Display five-number summary of each attribute and show it visually

Project: Students are encouraged to work on a good dataset in consultation with their faculty and apply the concepts learned in the course.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE COURSE: Microprocessors

Credit distribution, Eligibility and Pre-requisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Microprocessors	**4**	**3**	**0**	**1**	**Pass in XII class**	Computer System Architecture

Learning Objectives

This course introduces the internal architecture, programming models of Intel Microprocessors (8086 - Pentium) and assembly language programming. Students will also learn interfacing of memory and I/O devices with microprocessors.

Learning outcomes

On successful completion of the course, students will be able to:

- Describe the internal architecture of Intel microprocessors.
- Define and implement interfaces between the microprocessor and the devices.
- Write assembly language programs.

SYLLABUS OF DSE

Unit 1 (5 hours)

Microprocessor Architecture: Internal Architecture, Programming Model, Addressing Modes, Data Movement Instructions

Unit 2 (7 hours)

Microprocessor programming: Register Organization, instruction formats, Program control instructions, assembly language.

Unit 3 (10 hours)

Interfacing: Bus timings, Memory address decoding, cache memory and cache controllers, I/O interface, keyboard, timer, Interrupt controller, DMA controller, video controllers, communication interfaces.

Unit 4 (7 hours)

Data transfer schemes: Synchronous data transfer, asynchronous data transfer, interrupt driven data transfer, DMA mode data transfer.

Unit 5 (8 hours)

Microprocessor controllers: I/O controllers, interrupt controller, DMA controller, USART controller.

Unit 6 (8 hours)

Advanced microprocessor architecture: CISC architecture, RISC architecture, superscalar architecture, multicore architecture.

Essential/recommended readings

1. Brey, B.B. *The Intel Microprocessors: Architecture, Programming and Interfacing,* 8th edition, Pearson education, 2009.

2. Triebel, W.A., & Singh, A. *The 8088 and 8086 Microprocessors Programming, Interfacing, Software, Hardware and Applications*, 4th edition, Pearson education, 2002.

Additional References

1. Ramesh S Gaonkar *Microprocessor architecture, programming, and applications with the 8085,* 6th edition, Penram International Publishing, 2013.

Suggested Practical List (If any): (30 Hours)

Practical exercises such as

ASSEMBLY LANGUAGE PROGRAMMING

1. Write a program to print 'Hello World'.
2. Write a program to print two strings on two different lines.
3. Write a program to take a single digit number from the user and print that number on the console.
4. Write a program to compare two single digit numbers and check if they are equal or not.
5. Write a program for 8-bit addition of two single digit numbers. Show the result after ASCII adjust.
6. Write a program for 16-bit addition of two double digit numbers. Show the result after ASCII adjust.
7. Write a program for 16-bit BCD addition.
8. Write a program for 32-bit BCD addition and subtraction.
9. Write a program for 32-bit Binary addition,subtraction,multiplication and division.
10. Write a program for Binary to ASCII conversion.
11. Write a program for ASCII to Binary conversion.
12. Write a program to take input in an array and print it on the console.
13. Write a program to sort an array using bubble sort.
14. Write a program to perform linear search in an array.
15. Write a program to perform binary search in an array.
16. Write a program to add and subtract two arrays.
17. write programs to interface a microprocessor with external devices such as a keyboard and elevator.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

(Computer Science Courses for Undergraduate Programme of study with Computer Science discipline as one of the three Core Disciplines)

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSE 01a PYTHON Programming for Data Handling	**4**	**3**	**0**	**1**	Pass in Class XII	NIL

Learning Objectives

The course introduces students to the concept of data handling using files and GUI designing. This would equip the students with knowledge to work on real world data from various applications and GUI development for effective data handling.

Learning outcomes

On successful completion of the course, students will be able to:

- Learn constructs of Python language
- Perform data handling with files using Python.
- Design and implement GUI applications using Tkinter.

SYLLABUS OF DSE 01a

Unit 1 (15 Hours)

Introduction to Python Programming, Basic Constructs, and Python Built-in Data Structures: Introduction to Python programming language, Basic syntax, variables, and data types in Python, Functions and modular programming; Conditional statements (if, elif, else); Looping structures (for and while loops); Mutable and Immutable Data Structures, Strings-Indexing, slicing, traversal, operations; Lists-indexing, slicing, traversal, operations; tuples, dictionaries, and sets and their operations in Python

Unit 2 (5 Hours)

File Handling: Opening, reading, writing, and closing files; File modes and file object methods; Reading and writing text and binary files; Working with CSV files

Unit 3 (15 Hours)

Designing GUI Applications with Tkinter (15): What is Tkinter? Creating a Tkinter window, Layout managers, Tkinter widgets -Entry, Spinbox, Combobox, Checkbutton, Text, Button, LabelFrame; Implementing the application - LabelInput class, building of form, adding LabelFrame and other widgets, retrieving data from form, resetting form, building our application class.

Unit 4 (10 Hours)

Combining Python file handling and Tkinter: Creating a simple Tkinter application, Reading and writing to csv files in a Tkinter application

Essential/recommended readings

1. Taneja S., Kumar, N. Python Programming- A modular approach, 1st Edition, Pearson Education India, 2018,

2. Moore, Alan D. Python GUI Programming with Tkinter: Develop responsive and powerful GUI applications with Tkinter. Packt Publishing Ltd, 2021.

Additional References:

1. Guttag, J.V. Introduction to computation and programming using Python, 2nd edition, MIT

Online references/material:

1. https://docs.python.org/3/library/csv.html

Suggested Practical List (If any): (30 Hours)

Installing and setting up Python and relevant libraries; Python development environments (e.g., Anaconda, Jupyter Notebook)

1. Write a Python program to calculate the factorial of a number.
2. Write a Python program to generate prime numbers between 1 to n, where n is provided as input by the user.
3. Write a Python program to find the sum and average of numbers in a given list.
4. Given two sets, set1 and set2, write a Python program to find their union, intersection and difference.
5. Given a list of numbers, write a Python program to count the number of times an element occurs in a list and create a dictionary with *element:count* as *key:value* pairs.
6. Write a Python program to swap the first two and last two characters in a given string.
7. Write a Python program to create a text file having names of ten Indian cities.
8. Write a Python program to create a text file having atleast five lines about your college using `writelines()` function.
9. Write a Python program which reads the data from three input files having Employee Names and merges them into one output file.
10. Write a Python program to count the number of vowels in a file and write the *vowel : count* in a dictionary.
11. Write a Python program to create a CSV file having student data: RollNo, Enrollment No, Name, Course, Semester.
12. Write a Python program library to read the CSV file created in the above program and filter out records of II semester students.
13. Write a Python program using tkinter library to create a GUI to enter registration details for an event.
14. Write a Python program using tkinter library to create a calculator to perform addition, subtraction, multiplication and division of two numbers entered by the user.
15. Write a Python program using tkinter library to create an age calculator to calculate age when DOB is entered.
16. Write a Python program using tkinter library to read and write student data to and from a CSV file (refer question 11).

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Android Programming using Java	**4**	**3**	**0**	**1**	Pass in Class XII	NIL

Learning Objective

The course enables the students to understand Android architecture and its key features, making them competent to develop Android applications using Java.

Learning outcomes

On successful completion of the course, students will be able to:

- logically organize Java classes and interfaces using packages.
- understand the design of the Android operating system.
- design user interfaces using various dialog boxes, menus, etc.
- design Android applications with interaction among various activities/applications.

SYLLABUS OF DSE 01b

Unit 1 (15 hours)
Review of Object Oriented Programming and Java Fundamentals: Structure of Java programs, classes and objects, data types, type casting, looping constructs, inheritance.

Unit 2 (2 hours)
Interfaces: Interface basics, defining, implementing and extending interfaces.

Unit 3 (4 hours)
Packages: Basics of packages, creating and accessing packages.

Unit 4 (7 hours)

GUI Programming: AWT classes, event handling.

Unit 5 (5 hours)

Introduction to Android Programming: Introduction to Android Operating System, Android SDK, AVD, components of an Android Application, parcels, and bundles.

Unit 6 (6 hours)

User Interface Architecture: Android Architecture, Contexts in Android, Intents and Intent Filters, Activity Life Cycle, Activity Stack, Fragments, and Fragments Life Cycle.

Unit 7 (6 hours)

User Interface Design: Android Layouts, Views, Spinner, Menu, Toggle Buttons, Radio Buttons, Check Boxes, Alert Box, and Toasts.

Essential/recommended readings

1. Schildt H. Java: The Complete Reference. 12th edition. McGraw-Hill Education, 2021
2. Griffiths D. & Griffiths D. Head First Android Development. O'Reilly, 2017
3. Meier R. Professional AndroidTM 4 Application Development. John Wiley & Sons, Inc., 2012

Additional Resources:

1. Horstmann, C. S. Core Java - Vol. I – Fundamentals. 12th edition. Pearson Education, 2021
2. Murphy M. L. The Busy Coder's Guide to Android Development. CommonsWare, 2018
3. Phillips B., Stewart C., Hardy B. & Marsicano K. Android Programming: The Big Nerd Ranch Guide. Big Nerd Ranch, LLC, 2015
4. Sheusi J. C. Android Application Development for Java Programmers. Cengage Learning, 2013

Suggested Practical List (If any): (30 Hours)

1. Write a function to find whether a number is prime or not. Use this function to determine the nth prime number. Read n from the user.

2. Design a class Complex having a real part (x) and an imaginary part (y). Provide methods to perform the following on complex numbers:

    a. Add two complex numbers.

b. Multiply two complex numbers.

c. toString() method to display complex numbers in the form: x + i y

3. Create a class TwoDim which contains private members as x and y coordinates in package P1. Define the default constructor, a parameterized constructor and override toString() method to display the co-ordinates. Now reuse this class and in package P2 create another class ThreeDim, adding a new dimension as z as its private member. Define the constructors for the subclass and override toString() method in the subclass also. Write appropriate methods to show dynamic method dispatch. The main() function should be in a package P.

4. Write a program to create an Applet. Create a frame as a child of an applet. Implement mouseClicked( ), mouseEntered( ) and mouseExited( ) events for the applet. Frame is visible when mouse enters applet window and hidden when mouse exits from the applet window.

5. Write a program to display a string in a frame window with pink color as background.

6. Write a program to create an Applet that has two buttons named "Red" and "Blue". When a button is pressed, the background color of the applet is set to the color named by the button's label.

7. Create a "Hello World" application. That will display "Hello World" in the middle of the screen in the emulator. Also display "Hello World" in the middle of the screen in the Android Phone.

8. Create an Android application with a login module. (Check username and password).

9. Create a Spinner with strings taken from resource folder (res >> value folder) and on changing the spinner value, Image will change.

10. Create a Menu with 5 options and a selected option should appear in the text box.

11. Create an application with three option buttons, on selecting a button colour of the screen will change.

12. Create an Application to display various Activity and Fragment Life Cycle Methods.

13. Create an application with 2 fragments, one to set the background and other to set the fore-color of the text.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

COMMON POOL OF GENERIC ELECTIVES (GE) COURSES

GENERIC ELECTIVES : Database Management Systems

Credit distribution, Eligibility and Pre-requisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course	Department offering the course
		Lecture	Tutorial	Practical/ Practice			
Database Management Systems	4	3	0	1	**Pass in class XII**	NIL	**Computer Science**

Learning Objectives

The course introduces the students to the fundamentals of database management systems and their applications. Emphasis is given to the popular relational database system. Students will learn about the importance of database structure and its design using entity relationship diagrams and a formal approach using normalization. Basic concepts of file indexing and transaction processing will be taught. The course would give students hands-on practice with structured query language to create, manipulate, and implement a relational database.

Learning outcomes

On successful completion of the course, students will be able to:

- Use relational database management software to create and manipulate the database.
- Create conceptual data models using entity relationship diagrams for modeling real-life situations and map it to corresponding relational database schema.
- Use the concept of functional dependencies to remove redundancy and update anomalies.
- Apply normalization theory to get a normalized database scheme to get anomalies free databases.
- Write queries in relational algebra.
- Implement relational databases and formulate queries for data retrieval and data update problems using SQL.
- Learn the importance of index structures and concurrent execution of transactions in database systems.

SYLLABUS

Unit 1 (5 hours)

Introduction to Database: Database, characteristics of database approach, data models, database management system, three-schema architecture, components of DBMS, data independence, and file system approach vs. database system approach

Unit 2 (8 hours)

Entity Relationship Modeling: Conceptual data modeling - motivation, entities, entity types, attributes, relationships, relationship types, constraints on relationship, Entity Relationship diagram as conceptual data model.

Unit 3 (11 hours)

Relational Data Model: Data anomalies, Relational Data Model - Characteristics of a relation, schema-instance distinction, types of keys, relational integrity constraints. Relational algebra operators like selection, projection, cartesian product, join and write simple queries using them.

Unit 4 (10 hours)

Structured Query Language (SQL): DDL to create database and tables, table constraints, DML, Querying in SQL to retrieve data from the database, aggregation functions group by and having clauses, generate and query views.

Unit 5 (11 hours)

Database Design: Mapping an Entity Relationship diagram to corresponding relational database scheme, functional dependencies and Normal forms, 1NF, 2NF, and 3NF decompositions and desirable properties of them.

Essential/recommended readings

1. Elmasri, R., Navathe, B. S., *Fundamentals of Database Systems*, 7th Edition, Pearson Education, 2016.
2. Murach J., *Murach's MySQL,* 3th Edition, Pearson, 2019.

Additional References

1. Connolly T. M., Begg C. E. *Database Systems: A Practical Approach to Design, Implementation, and Management*, 6th edition, Pearson, 2019.
2. Ramakrishnan R., Gehrke J. *Database Management Systems*, 3rd Edition, McGraw-Hill, 2014.
3. Silberschatz A., Korth H.F., Sudarshan S. *Database System Concepts*, 7th Edition, McGraw Hill, 2019.

Suggested Practical List (if any): (30 hours)

Practical exercises based on a given schema.

Create and use the following student-course database schema for a college to answer the given queries using the standalone SQL editor.

STUDENT	<u>**Roll No**</u>	**Student Name**	**Course ID**	**DOB**
	Char(6)	Varchar(20)	Varchar(10)	Date

COURSE	<u>**CID**</u>	**Course Name**	**Course Type**	**Teacher-in-charge**	**Total Seats**	**Duration**
	Char(6)	Varchar (20)	Char (8)	Varchar (15)	Unsigned int	Unsigned int

ADMISSION	<u>**Roll No**</u>	<u>**CID**</u>	**Date of Admission**
	Char(6)	Char(6)	**Date**

Here, Rollno (ADMISSION) and SID (ADMISSION) are foreign keys. Note that course type may have two values viz. Fulltime and Parttime and a student may enroll in any number of courses

1. Retrieve names of students enrolled in any course.
2. Retrieve names of students enrolled in at least one part time course.
3. Retrieve students' names starting with letter 'A'.
4. Retrieve students' details studying in courses 'computer science' or 'chemistry'.
5. Retrieve students' names whose roll no either starts with 'X' or 'Z' and ends with '9'
6. Find course details with more than N students enrolled where N is to be input by the user.
7. Update student table for modifying a student name.
8. Find course names in which more than five students have enrolled
9. Find the name of youngest student enrolled in course 'BSc(P)CS'
10. Find the name of most popular society (on the basis of enrolled students)
11. Find the name of two popular part time courses (on the basis of enrolled students)
12. Find the student names who are admitted to full time courses only.
13. Find course names in which more than 30 students took admission
14. Find names of all students who took admission to any course and course names in which at least one student has enrolled
15. Find course names such that its teacher-in-charge has a name with 'Gupta' in it and the course is full time.
16. Find the course names in which the number of enrolled students is only 10% of its total seats.
17. Display the vacant seats for each course
18. Increment Total Seats of each course by 10%
19. Add enrollment fees paid ('yes'/'No') field in the enrollment table.
20. Update the date of admission for all the courses by 1 year.
21. Create a view to keep track of course names with the total number of students enrolled in it.

22. Count the number of courses with more than 5 students enrolled for each type of course.
23. Add column Mobile number in student table with default value '9999999999'
24. Find the total number of students whose age is > 18 years.
25. Find names of students who are born in 2001 and are admitted to at least one part time course.
26. Count all courses having 'science' in the name and starting with the word 'BSc'.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

GENERIC ELECTIVES : Java Programming

Credit distribution, Eligibility and Pre-requisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course	Department offering the course
		Lecture	Tutorial	Practical/ Practice			
GE: Java Programming	**4**	**3**	**0**	**1**	**Pass in class XII**	NIL	**Computer Science**

Learning Objectives

This course is designed to develop understanding of object-oriented programming concepts like Classes, Objects, Inheritance and Polymorphism using Java. The course provides understanding of multithreading and exception handling in Java. It also introduces how to create Java applications with graphical user interface (GUI).

Learning outcomes

On completion of this course, the student will be able to:

- Understand the object-oriented concepts – Classes, Objects, Inheritance, Polymorphism– for problem solving.
- Create and handle multithreading.
- Handle program exceptions.
- Handle input/output through files.
- Create Java applications with a graphical user interface (GUI).

SYLLABUS OF GE

Unit 1 (6 hours)

Introductory Concepts: program, identifiers, variables, constants, primitive data types, expressions, Naming Conventions, Type casting, operators, control statements, structured data types, arrays, functions.

Unit 2 (13 hours)

Object Oriented Concepts: Abstraction, encapsulation, objects, classes, methods, constructors, inheritance, polymorphism, static and dynamic binding, Anonymous block, Static Data members, overloading and overriding, Usage of super and this keyword, Abstract classes, Interfaces and Packages, Access modifiers, Object class

Unit 3 (11 hours)

Multithreading: Creating Threads, Thread Priority, Blocked States, Extending Thread Class, Runnable Interface, Starting Threads, Thread Synchronization, Sync Code Block, Overriding Synced Methods, Thread Communication, wait, notify and notify all.

Unit 4 (8 hours)

Introduction to Exception handling: Exception and Error, Throw, try and catch Blocks, Exception handlers, java.lang Exceptions, Built-InExceptions.

Unit 5 (7 hours)

Introduction to File Handling: Byte Stream, Character Stream, File I/O Basics, File Operations, Serialization.

Essential/recommended readings

1. Cay S. Horstmann, *Core Java - Vol. I – Fundamentals*, 10th edition, Pearson, 2017.
2. James Gosling, Bill Joy, Guy L. Steele Jr, Gilad Bracha, Alex Buckley, *The Java Language Specification*, *Java SE* 7th edition, Addison-Wesley, 2011

Additional References

1. Herbert Schildt, *Java: The Complete Reference*, 10th edition, McGraw-Hill Education, 2018.

2 Richard Johnson, *An Introduction to Java Programming and Object-Oriented Application Development*, Thomson Learning, 2006.

3. Kathy Sierra and Bert Bates, *Head First Java*, 3rd edition, O'Reilly, 2022.

Suggested Practical List (If any): (30 Hours)

Practical exercises such as

1. Create a java program to implement stack and queue concepts.
2. Write a program to take input from command line arguments.
3. Write a java program to show static and dynamic polymorphism.
4. Write a java program to show multiple inheritance using interfaces.
5. Write a program in java to show the chaining of execution of construction.
6. Write a java program to show multithreaded producer and consumer applications.
7. write a program in java to synchronize the multithreaded application
8. Create a customized exception and also make use of all the exception keywords.
9. Write a program to show different ways to get input from user
10. Design a form using AWT components and the Frame container.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

(Computer Science Courses for Undergraduate Programme of study with Computer Science discipline as one of the three Core Disciplines)

DISCIPLINE SPECIFIC CORE COURSE (DSC-3): Computer System Architecture

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC03: Computer System Architecture	4	3	0	1	Passed 12th class with Mathematics	NIL

Learning Objectives

This course introduces students to the fundamental concepts of digital computer organization, design, and architecture. It aims to develop a basic understanding of the building blocks of a computer system and highlights how these blocks are organized together to architect a digital computer system.

Learning outcomes

On successful completion of the course, students will be able to:

- Design combinatorial circuits using basic building blocks. Simplify these circuits using Boolean algebra and Karnaugh maps. Differentiate between combinational circuits and sequential circuits.
- Represent data in binary form, convert numeric data between different number systems, and perform arithmetic operations in binary.
- Determine various stages of the instruction cycle and describe interrupts and their handling.
- Explain how the CPU communicates with memory and I/O devices.
- Simulate the design of a basic computer using a software tool.

SYLLABUS OF DSC-3

Unit 1 (9 hours)

Digital Logic Circuits: Digital Logic Gates, Flip flops and their characteristic table, Logic circuit simplification using Boolean algebra and Karnaugh map, Don't care conditions, Combinational circuits, Introduction to Sequential Circuits

Unit 2 (7 hours)

Digital Components: Decoders, Encoders, Multiplexers, Binary Adder, Binary Adder Subtractor, Binary Incrementor, Registers, and Memory Units

Unit 3 (13 hours)

Data Representation: Binary representation of both numeric and alphanumeric data, representation of numeric data in different number systems, (Binary, Octal, Decimal and Hexadecimal), conversion from one number system to another, complements, representation of signed and unsigned numbers, addition and subtraction of signed and unsigned numbers and overflow detection.

Unit 4 (9 hours)

Basic Computer Organization and Design: Stored program organization, Computer registers, Instruction set and their completeness, Instruction cycle, Memory reference instructions, Register reference instructions, Input- Output reference instructions, Interrupt cycle, Addressing modes.

Unit 5 (7 hours)

Input-Output Organization: I/O interface, I/O vs. Memory Bus, Isolated I/O, Memory Mapped I/O, Direct Memory Access.

Essential/recommended readings

1. M. Morris Mano, *Computer System Architecture*, 3rd edition, Pearson Education, 2017.
2. Linda Null, Julia Lobur, *Essentials of Computer Organization and Architecture*, 5th Edition, 2019.

Additional References

1. D. Comer, *Essentials of Computer Architecture,* 2nd edition, CRC Press, 2017.

Suggested Practical List (If any): (30 Hours)

Practical exercises such as

(Use Simulator – CPU Sim 3.6.9 or any higher version for the implementation)

1. Create a machine based on the following architecture:

Registers

IR	DR	AC	AR	PC	I	E
16 bits	16 bits	16 bits	12 bits	12 bits	1 bit	1 bit

Memory 4096 words	

16 bits per word	Instruction format 15 12 11 0 | Opcode | Address |

Basic Computer Instructions

Memory Reference			Register Reference	
Symbol	Hex		Symbol	Hex
AND	0xxx	Direct Addressing	CLA	7800
ADD	1xxx		CLE	7400
LDA	2xxx		CMA	7200
STA	3xxx		CME	7100
			HLT	7001

Refer to Chapter-5 for a description of the instructions.

Design the register set, the memory, and the instruction set. Use this machine for the assignments in this section.

1. Implement fetch sequence
2. Write an assembly program to simulate the addition of two numbers when one is stored in memory and another is entered by the user.
3. Write an assembly program to simulate addition of two numbers when both numbers are taken as inputs from user.
4. Write an assembly program to simulate subtraction of two numbers when one number is stored in memory and another is entered by the user.

5. Write an assembly program to simulate subtraction of two numbers when both numbers are taken as inputs from user
6. Write an assembly program to simulate the following logical operations on two user-entered numbers.

   i.AND

   ii.OR

   iii.NOT

7. Write an assembly language program to simulate the machine for following register reference instructions and determine the contents of AC, E, PC, AR and IR registers in decimal after the execution:

   i. CLE

   ii. CLA

   iii. CMA

   iv. CME

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

Computer Science Courses for Undergraduate Programme of study with Computer Science discipline as one of the two Core Disciplines
(For e.g. courses for B.A. Programmes with Computer Science as Major discipline)

DISCIPLINE SPECIFIC CORE COURSE (DSC-3): Computer System Architecture

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC03: Computer System Architecture	4	3	0	1	Passed 12th class with Mathematics	NIL

Learning Objectives

This course introduces students to the fundamental concepts of digital computer organization, design, and architecture. It aims to develop a basic understanding of the building blocks of a computer system and highlights how these blocks are organized together to architect a digital computer system.

Learning outcomes

On successful completion of the course, students will be able to:

- Design combinatorial circuits using basic building blocks. Simplify these circuits using Boolean algebra and Karnaugh maps. Differentiate between combinational circuits and sequential circuits.
- Represent data in binary form, convert numeric data between different number systems, and perform arithmetic operations in binary.
- Determine various stages of the instruction cycle and describe interrupts and their handling.
- Explain how the CPU communicates with memory and I/O devices.
- Simulate the design of a basic computer using a software tool.

SYLLABUS OF DSC-3

Unit 1 (9 hours)

Digital Logic Circuits: Digital Logic Gates, Flip flops and their characteristic table, Logic circuit simplification using Boolean algebra and Karnaugh map, Don't care conditions, Combinational circuits, Introduction to Sequential Circuits

Unit 2 (7 hours)

Digital Components: Decoders, Encoders, Multiplexers, Binary Adder, Binary Adder Subtractor, Binary Incrementor, Registers, and Memory Units

Unit 3 (13 hours)

Data Representation: Binary representation of both numeric and alphanumeric data, representation of numeric data in different number systems, (Binary, Octal, Decimal and Hexadecimal), conversion from one number system to another, complements, representation of signed and unsigned numbers, addition and subtraction of signed and unsigned numbers and overflow detection.

Unit 4 (9 hours)

Basic Computer Organization and Design: Stored program organization, Computer registers, Instruction set and their completeness, Instruction cycle, Memory reference instructions, Register reference instructions, Input- Output reference instructions, Interrupt cycle, Addressing modes.

Unit 5 (7 hours)

Input-Output Organization: I/O interface, I/O vs. Memory Bus, Isolated I/O, Memory Mapped I/O, Direct Memory Access.

Essential/recommended readings

1. M. Morris Mano, *Computer System Architecture*, 3rd edition, Pearson Education, 2017.
2. Linda Null, Julia Lobur, *Essentials of Computer Organization and Architecture*, 5th Edition, 2019.

Additional References

2. D. Comer, *Essentials of Computer Architecture,* 2nd edition, CRC Press, 2017.

Suggested Practical List (If any): (30 Hours)

Practical exercises such as

(Use Simulator – CPU Sim 3.6.9 or any higher version for the implementation)

1. Create a machine based on the following architecture:

Registers

IR	DR	AC	AR	PC	I	E
16 bits	16 bits	16 bits	12 bits	12 bits	1 bit	1 bit

Memory 4096 words	

16 bits per word	Instruction format 15 12 11 0 Opcode | Address

Basic Computer Instructions

Memory Reference			Register Reference	
Symbol	Hex		Symbol	Hex
AND	0xxx	Direct Addressing	CLA	7800
ADD	1xxx		CLE	7400
LDA	2xxx		CMA	7200
STA	3xxx		CME	7100
			HLT	7001

Refer to Chapter-5 for a description of the instructions.

Design the register set, the memory, and the instruction set. Use this machine for the assignments in this section.

1. Implement fetch sequence
2. Write an assembly program to simulate the addition of two numbers when one is stored in memory and another is entered by the user.
3. Write an assembly program to simulate addition of two numbers when both numbers are taken as inputs from user.
4. Write an assembly program to simulate subtraction of two numbers when one number is stored in memory and another is entered by the user.

5. Write an assembly program to simulate subtraction of two numbers when both numbers are taken as inputs from user
6. Write an assembly program to simulate the following logical operations on two user-entered numbers.

    i.AND

    ii.OR

    iii.NOT

7. Write an assembly language program to simulate the machine for following register reference instructions and determine the contents of AC, E, PC, AR and IR registers in decimal after the execution:

    i. CLE

    ii. CLA

    iii. CMA

    iv. CME

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE : Data Mining-I

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CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Data Mining - I	4	3	0	1	Passed 12th class with Mathematics	Programming using Python

Learning Objectives

This course aims to introduce data mining techniques and their application on real-life datasets. The students will learn to pre-process the dataset and make it ready for application of data mining techniques. The course will focus on three main techniques of data mining i.e. Classification, Clustering and Association Rule Mining. Different algorithms for these techniques will be discussed along with appropriate evaluation metrics to judge the performance of the results delivered.

Learning outcomes

On successful completion of the course, students will be able to:

- Pre-process the data for subsequent data mining tasks
- Apply a suitable classification algorithm to train the classifier and evaluate its performance.
- Apply appropriate clustering algorithm to cluster the data and evaluate clustering quality
- Use association rule mining algorithms and generate frequent item-sets and association rules

SYLLABUS

Unit 1 (8 hours)

Introduction to Data Mining: Motivation and Challenges for data mining, Types of data mining tasks, Applications of data mining, Data measurements, Data quality, Supervised vs. unsupervised techniques

Unit 2 (9 hours)

Data Pre-Processing: Data aggregation, sampling, dimensionality reduction, feature subset selection, feature creation, variable transformation.

Unit 3 (11 hours)

Cluster Analysis: Basic concepts of clustering, measure of similarity, types of clusters and clustering methods, K-means algorithm, measures for cluster validation, determine optimal number of clusters

Unit 4 (8 hours)

Association Rule Mining: Transaction data-set, frequent itemset, support measure, rule generation, confidence of association rule, Apriori algorithm, Apriori principle

Unit 5 (9 hours)

Classification: Naive Bayes classifier, Nearest Neighbour classifier, decision tree, overfitting, confusion matrix, evaluation metrics and model evaluation.

Essential/recommended readings

1. Tan P.N., Steinbach M, Karpatne A. and Kumar V. *Introduction to Data Mining,* 2nd edition, Pearson, 2021.
2. Han J., Kamber M. and Pei J. *Data Mining: Concepts and Techniques*, 3rd edition, 2011, Morgan Kaufmann Publishers.
3. Zaki M. J. and Meira J. Jr. *Data Mining and Machine Learning: Fundamental Concepts and Algorithms*, 2nd edition, Cambridge University Press, 2020.

Additional References

1. Aggarwal C. C. *Data Mining: The Textbook*, Springer, 2015.

2. Dunham M. *Data Mining: Introductory and Advanced Topics,* 1st edition, Pearson Education India, 2006.

Recommended Datasets for :

Classification: Abalone, Artificial Characters, Breast Cancer Wisconsin (Diagnostic)

Clustering: Grammatical Facial Expressions, HTRU2, Perfume data

Association Rule Mining: MovieLens, Titanics

Suggested Practicals List (If any): (30 Hours)

Practical exercise such as

1. Apply data cleaning techniques on any dataset (e,g, wine dataset). Techniques may include handling missing values, outliers, inconsistent values. A set of validation rules can be prepared based on the dataset and validations can be performed.
2. Apply data pre-processing techniques such as standardization/normalization, transformation, aggregation, discretization/binarization, sampling etc. on any dataset
3. Run Apriori algorithm to find frequent itemsets and association rules on 2 real datasets and use appropriate evaluation measures to compute correctness of obtained patterns
    a) Use minimum support as 50% and minimum confidence as 75%
    b) Use minimum support as 60% and minimum confidence as 60 %

4. Use Naive bayes, K-nearest, and Decision tree classification algorithms and build classifiers on any two datasets. Divide the data set into training and test set. Compare the accuracy of the different classifiers under the following situations:
    I. a) Training set = 75% Test set = 25% b) Training set = 66.6% (2/3rd of total), Test set = 33.3%
    II. Training set is chosen by i) hold out method ii) Random subsampling iii) Cross-Validation. Compare the accuracy of the classifiers obtained.

    Data is scaled to standard format.
5. Use Simple K-means algorithm for clustering on any dataset. Compare the performance of clusters by changing the parameters involved in the algorithm. Plot MSE computed after each iteration using a line plot for any set of parameters.

Project: Students should be promoted to take up one project on any UCI/kaggle/data.gov.in or a dataset verified by the teacher. Preprocessing steps and at least one data mining technique should be shown on the selected dataset. This will allow the students to have a practical knowledge of how to apply the various skills learnt in the subject for a single problem/project.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

Computer Science Courses for Undergraduate Programme of study with Computer Science discipline as one of the two Core Disciplines

(For e.g. courses for B.A. Programmes with Computer Science as Non-major Discipline)

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
DSC03: Computer System Architecture	4	3	0	1	Passed 12th class with Mathematics	NIL

Learning Objectives

This course introduces students to the fundamental concepts of digital computer organization, design, and architecture. It aims to develop a basic understanding of the building blocks of a computer system and highlights how these blocks are organized together to architect a digital computer system.

Learning outcomes

On successful completion of the course, students will be able to:

- Design combinatorial circuits using basic building blocks. Simplify these circuits using Boolean algebra and Karnaugh maps. Differentiate between combinational circuits and sequential circuits.
- Represent data in binary form, convert numeric data between different number systems, and perform arithmetic operations in binary.
- Determine various stages of the instruction cycle and describe interrupts and their handling.
- Explain how the CPU communicates with memory and I/O devices.
- Simulate the design of a basic computer using a software tool.

SYLLABUS OF DSC-3

Unit 1 (9 hours)

Digital Logic Circuits: Digital Logic Gates, Flip flops and their characteristic table, Logic circuit simplification using Boolean algebra and Karnaugh map, Don't care conditions, Combinational circuits, Introduction to Sequential Circuits

Unit 2 (7 hours)

Digital Components: Decoders, Encoders, Multiplexers, Binary Adder, Binary Adder Subtractor, Binary Incrementor, Registers, and Memory Units

Unit 3 (13 hours)

Data Representation: Binary representation of both numeric and alphanumeric data, representation of numeric data in different number systems, (Binary, Octal, Decimal and Hexadecimal), conversion from one number system to another, complements, representation of signed and unsigned numbers, addition and subtraction of signed and unsigned numbers and overflow detection.

Unit 4 (9 hours)

Basic Computer Organization and Design: Stored program organization, Computer registers, Instruction set and their completeness, Instruction cycle, Memory reference instructions, Register reference instructions, Input- Output reference instructions, Interrupt cycle, Addressing modes.

Unit 5 (7 hours)

Input-Output Organization: I/O interface, I/O vs. Memory Bus, Isolated I/O, Memory Mapped I/O, Direct Memory Access.

Essential/recommended readings

1. M. Morris Mano, *Computer System Architecture*, 3rd edition, Pearson Education, 2017.
2. Linda Null, Julia Lobur, *Essentials of Computer Organization and Architecture*, 5th Edition, 2019.

Additional References

3. D. Comer, *Essentials of Computer Architecture,* 2nd edition, CRC Press, 2017.

Suggested Practical List (If any): (30 Hours)

Practical exercises such as

(Use Simulator – CPU Sim 3.6.9 or any higher version for the implementation)

1. Create a machine based on the following architecture:

Registers

IR	DR	AC	AR	PC	I	E
16 bits	16 bits	16 bits	12 bits	12 bits	1 bit	1 bit

Memory 4096 words 16 bits per word	Instruction format 15 12 11 0

	Opcode | Address

Basic Computer Instructions

<table>
<tr><th colspan="3">Memory Reference</th><th colspan="2">Register Reference</th></tr>
<tr><th>Symbol</th><th colspan="2">Hex</th><th>Symbol</th><th>Hex</th></tr>
<tr><td>AND</td><td>0xxx</td><td rowspan="5">Direct Addressing</td><td>CLA</td><td>7800</td></tr>
<tr><td>ADD</td><td>1xxx</td><td>CLE</td><td>7400</td></tr>
<tr><td>LDA</td><td>2xxx</td><td>CMA</td><td>7200</td></tr>
<tr><td rowspan="2">STA</td><td rowspan="2">3xxx</td><td>CME</td><td>7100</td></tr>
<tr><td>HLT</td><td>7001</td></tr>
</table>

Refer to Chapter-5 for a description of the instructions.

Design the register set, the memory, and the instruction set. Use this machine for the assignments in this section.

1. Implement fetch sequence
2. Write an assembly program to simulate the addition of two numbers when one is stored in memory and another is entered by the user.
3. Write an assembly program to simulate addition of two numbers when both numbers are taken as inputs from user.
4. Write an assembly program to simulate subtraction of two numbers when one number is stored in memory and another is entered by the user.
5. Write an assembly program to simulate subtraction of two numbers when both numbers are taken as inputs from user
6. Write an assembly program to simulate the following logical operations on two user-entered numbers.

i.AND

ii.OR

iii.NOT

7. Write an assembly language program to simulate the machine for following register reference instructions and determine the contents of AC, E, PC, AR and IR registers in decimal after the execution:

i. CLE

ii. CLA

iii. CMA

iv. CME

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DEPARTMENT OF OPERATIONAL RESEARCH

B.SC. (HONS) OPERATIONAL RESEARCH

Category I

DISCIPLINE SPECIFIC CORE COURSE – 7: CONVEX AND DISCRETE OPTIMIZATION

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Convex and Discrete Optimization (DSC-7)	4	3	1	0	Passed 12th class with Mathematics	Linear Programming

Learning Objectives:

- To impart knowledge about the formulations and solution techniques of integer linear and multi-objective goal programming problems.

Learning Outcomes:

On successful completion of the course, students will be able to:

- Identify different types of optimization problems which occur in real life and their characteristics.
- Explain the theoretical concepts related to unconstrained optimization problems and demonstrate optimality conditions and solution approaches for them.
- Develop the concepts of a multi-objective programming problem and demonstrate its solution using goal programming.
- Formulate real-life problems as integer linear programming problems and solve them using Branch and Bound method.

SYLLABUS OF DSC-7

Unit I: Unconstrained Optimization **(8 Hours)**

Single and multiple variable problems, Necessary and sufficient conditions for finding extrema, Solution methods: Bisection, Newton, Golden section, Gradient search.

Unit II: **Convex Functions** **(12 Hours)**

Local and global maxima/minima for functions of one and two variables, inflection point, positive/negative definite and semi-definite matrices, convex/concave functions, and their properties, Verifying convexity/concavity through a Hessian matrix.

Unit III: Goal Programming **(12 Hours)**

Goal Programming: Basics of goal programming, Weighted and pre-emptive goal programming, Formulation of a goal programming problem, Graphical solution method, Modified Simplex method.

Unit IV: Integer Linear Programming **(13 Hours)**

Introduction to Integer linear programming problem (ILPP), Pure ILPP, Mixed ILPP, and 0-1 ILPP, Applications of ILPP: Capital budgeting, problem Fixed charge problem, Travelling salesman problem, Media allocation, Knapsack problem, Gomory's cutting plane method, Branch and bound method.

References:

1. Chandra, S., Jayadeva, & Mehra, A. (2013). *Numerical optimization with applications.* New Delhi: Narosa Publishing House.
2. Ravindran, A., Phillips, D. T., & Solberg, J. J. (2007). *Operations research- principles and practice* (2nd ed.). New Delhi: Wiley India (Indian print).
3. Sinha, S. M. (2006). *Mathematical programming- theory and methods* (1st ed.). New Delhi: Elsevier Science (Indian print).

Practical component (if any) – NIL

Essential Readings:

- Bazaraa, M. S., Sherali, H. D., & Shetty, C. M. (2006). *Nonlinear programming-Theory and algorithms (3rd ed.).* New Delhi: John Wiley & Sons (Indian print).
- Chandra, S., Jayadeva, & Mehra, A. (2009). *Numerical optimization with applications*. New Delhi: Narosa Publishing House.

Suggested Readings:

- Antoniou, A., & Lu, Wu-Sheng (2007). *Practical optimization- Algorithms and engineering applications*. New York: Springer.
- Hillier, F. S., & Lieberman, G. J. (2010). *Introduction to operations research- Concepts and cases (9th ed.).* New Delhi: Tata McGraw Hill (Indian print).

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE – 8: ADVANCED CALCULUS

Credit distribution, Eligibility and Pre-requisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Advanced Calculus (DSC-8)	4	3	1	0	Passed 12th class with Mathematics	Calculus

Learning Objectives

The Learning Objectives of this course are as follows:

- To acquaint the students with the advanced concepts in Calculus
- To make the students learn effective methods of calculus
- To make the student understand the quantitative change in the behaviour of the variables and apply them on the problems related to Operational Research domain

Learning Outcomes

On successful completion of the course, students will be able to:

- Understand the concepts of function of one variable to functions of two or more variables.
- Evaluate double integral based problems
- Analyse integration based problems in real life cases.
- Understand Calculus.

SYLLABUS OF DSC-8

Unit I: Differential calculus **(15 Hours)**

Function of Two Variables, Limits and continuity, Partial differentiation, Total differential, Approximation, Higher order partial derivative, Homogeneous Function, Taylor's Theorem for two variables, Maxima and Minima for functions of Two Variables, Lagrange Multiplier and Constrained optimization.

Unit II: Integral calculus **(10 Hours)**
Double Integral, Double Integration over rectangular and nonrectangular regions, Change of variables in integrals.

Unit III: Differential equations **(20 Hours)**
Order and degree of a differential equation, Exact differential equations, Differential equations of first order and first degree, Higher Order Differential Equations: Homogeneous linear differential equations of order n with constant coefficients, The Cauchy-Euler's equation of order n, Method of variation of parameters, Application of differential equations to operational research problems.

Practical component (if any) – Nil

Essential/recommended readings

- Strauss, M. J., Bradley, G. L., & Smith, K. J. (2007). *Calculus* (3rd Edition). Dorling Kindersley (India) Pvt. Ltd. (Pearson Education). Delhi. Sixth impression 2011.
- Ross, Shepley. L. (1984). Differential equations (3rd ed.). John Wiley & Sons.
- Kreyszig, E. (2007). *Advanced Engineering Mathematics* (9th Edition). Wiley Plus Set (p. 334). John Wiley & Sons.
- Marsden, J., & Weinstein, A. (1985). *Calculus I*. Springer Science & Business Media.
- Yamada, S. (2014). *Software Reliability Modeling: Fundamentals and Applications*. Tokyo: Springer.

Suggestive readings

- Shanti Narayan and P K Mittal (2018). *Differential Calculus. 15th Ed (Revised).*, S Chand Publication, New Delhi
- Shanti Narayan and P K Mittal (2016). *Integral Calculus. 11th Ed (Revised*), S Chand Publication, New Delhi.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE – 9: QUEUING THEORY

Credit distribution, Eligibility and Pre-requisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Queuing Theory (DSC-9)	**4**	**3**	**0**	**1**	**Passed 12th class with Mathematics**	**Probability and Statistics**

Learning Objectives

The Learning Objectives of this course are as follows:

- To introduce queuing (waiting lines) models and their applications in real-life situations.
- To provide necessary mathematical support and confidence to the students to tackle real life problems.
- To make students learn both theory and applications of fundamental and advanced models in this field.

Learning outcomes

On successful completion of the course, students will be able to:

- Understand the concepts of stochastic processes, Markov processes, Markov chains and apply these in analysing queuing systems.
- Understand the concepts and analyse the mathematical theory related to queuing systems.
- Analyse and compute quantitative measures of performance for queuing systems.
- Apply and extend queuing models to analyse real world systems.

SYLLABUS OF DSC-9

Unit I: Queueing systems **(6 Hours)**

Basic characteristics, measures of performance and Kendall's notation. Little's formula, traffic intensity.

Unit II: Stochastic processes **(10 Hours)**

Definition and classification on the basis of state and parameter space. Markov chain: definition, transition probability matrix (TPM), classification of states. Continuous-time

Markov chains: Poisson process (definition and its relationship with exponential distribution), pure birth process and pure death process.

Unit III: Markovian queueing models (20 Hours)

General birth-death processes, single-server queue (M/M/1), multi-server queue (M/M/c), queue with finite capacity (M/M/c/K), Erlang's loss formula (M/M/c/c), queues with unlimited service (M/M/∞), finite-source queues, queues with impatience (M/M/1 with balking and M/M/1 with reneging).

Unit IV: Decision problems in queueing theory (9 Hours)

Descriptive and prescriptive modeling, performance measures of decision-making, queueing design problems, queueing control problems.

Practical component (if any) – (30 Hours)

- Finding measures of performance for deterministic queuing system.
- Finding measures of performance for M/M/1 queuing system with infinite capacity.
- Finding measures of performance for M/M/1 queuing system with finite capacity.
- Finding measures of performance for M/M/c queuing system with infinite capacity.
- Finding measures of performance for M/M/c queuing system with finite capacity.
- Finding measures of performance for any Markovian queuing system with multiple servers and with finite/infinite capacity.

Essential/recommended readings

- Cooper, R. B. (1981). *Introduction to Queueing Theory* (2nd Edition). North Holland.
- Kleinrock L. (1975). *Queueing Systems*, Volume 1: Theory, John Wiley.
- Gross, Donald, Shortle , John F., Thompson, James M., and Harris, Carl M. (2008). *Fundamentals of Queueing Theory* (5th Edition), John Wiley and Sons Inc. Pte. Ltd.
- Bhat, U. N. (2008). *An introduction to Queueing Theory: Modelling and Analysis in Applications (Statistics for Industry and Technology)*. Birkhauser Boston.
- Cox, D. R. and Smith ,W. L. (1991). *Queues*. Chapman and Hall/CRC.
- Medhi, J. (2002). *Stochastic Models in Queueing Theory* (2nd Edition), Academic Press.
- Satty, T. L. (1983). *Elements of Queueing Theory with Applications*, Dover Publications, NY.
- Prabhu, N. U. (2012). *Foundations of Queueing Theory (International Series in Operations Research & Management Science)*, Springer.

Suggestive readings-Nil

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

Category II

(B.A. Programme with Operational Research as Major discipline)

DISCIPLINE SPECIFIC CORE COURSE – 5: Mathematical Modelling for Business

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Mathematical Modelling for Business (DSC-5)	4	3	0	1	Passed 12th class with Mathematics	Linear Programming

Learning Objectives

To acquaint students with different mathematical modelling techniques applicable in various businesses viz., inventory control, marketing management, and network flow analysis.

Learning outcomes

On successful completion of the course, students will be able to:

- Explain the meaning of Inventory control, its various forms, and the functional role of Inventory.
- Calculate the Economic Order Quantity (EOQ) for various Deterministic Inventory models.
- Comprehend inventory models with All Units Quantity Discounts
- Gain an understanding of the basic concepts and issues in marketing and their application in business decisions.
- Gain an understanding of network analysis and related mathematical models.
- Use standard methodologies for solving network flow problems.

SYLLABUS OF DSC-5

Unit I: Introduction to Inventory Management (18 Hours)

Concept and significance of inventory management, Different types of costs in the inventory system. Deterministic continuous review models: Economic order quantity (EOQ) model with and without shortages, Finite replenishment rate Inventory models without and with planned shortages. Determination of reorder point for all the models. Inventory models with All Units Quantity Discounts.

Unit II: Fundamentals for Marketing Management **(15 Hours)**
Nature, Scope, and Importance of Marketing, Basic concepts, Marketing Environment, Consumer Behaviour, Market Classification based on Competitive Conditions, Product Mix, Pricing Strategies, Media allocation for advertisement, Brand switching analysis, Concept of Measurement of Elasticity of Demand, Factors Affecting Elasticity of Demand, Income Elasticity of Demand, Cross Elasticity of Demand, Advertising Elasticity of Demand.

Unit III: Network Analysis **(12 Hours)**
Understanding of network components, Construction of network diagram, Introduction to Network flow problems and their applications: Shortest path problem, Travelling salesman problem, minimum spanning tree.

Practical component (if any) - **(30 Hours)**
Practical/Lab to be performed on a computer using OR/Statistical packages

- To find optimal inventory policy for deterministic inventory models without shortages.
- To find optimal inventory policy for deterministic inventory models without shortages.
- To solve all units quantity discounts model.
- Finding shortest path in a network.
- Solving a travelling salesman problem.
- Finding minimum spanning tree in a network.
- Problems based on media allocation for advertisement.
- Problems based on Brand switching analysis.

Essential/recommended readings

- Bazaraa, M. S., Jarvis, J. J., & Sherali, H. D. (2011). Linear programming and network flows. John Wiley & Sons.
- Hadley, G., & Whitin, T. M. (1963). *Analysis of inventory systems*. Prentice-Hall.
- Waters, D. (2008). *Inventory control and management.* (2nd Edition). John Wiley & Sons.
- Kotler P., & Keller, K. L. (2008), *Marketing management* (13th ed.). New Delhi: Pearson Education, Ltd.

Suggestive readings Nil

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE – 6: Python Programming

Credit distribution, Eligibility and Pre-requisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Python Programming (DSC-6)	4	3	0	1	Passed 12th class with Mathematics	Nil

Learning Objectives

The Learning Objectives of this course are as follows:

- To introduce the basic concepts of Python programming. The course will familiarize the students with Python's ability to handle different data formats such as numbers, strings, lists, dictionaries, sets, tuples, etc.
- The students will be made familiar with the concepts of loops. Modularization of code using inbuilt functions as well as user defined functions will also be explained.
- To introduce the basics for various useful libraries so as to equip the students with modern computing skills.

Learning outcomes

On successful completion of the course, students will be able to:

- Learn Python installation and configuration.
- Understand simple scripting using Python.
- Learn Syntax and Semantics of Python Programming.
- Understand different data types and arithmetical, logical and relational expressions in Python.
- Understand the control structures and functions in Python by writing codes for some real-world problems.
- Handle simple data structures, lists, dictionaries, sets and tuples.
- Modularize the code using inbuilt functions and user defined functions.
- Handle various managerial decision making related problems

SYLLABUS OF DSC-6

Unit I: Introduction **(6 Hours)**

Python installation, Basic Terminal Commands, interactive mode and script mode, Structure of a Program, Simple Python Script Writing, script execution, debugging errors and understanding simple programs in Python

Unit II: Understanding Control Statements **(6 Hours)**
Identifiers and keywords; literals, numbers, and strings; Operators and expressions; Input and Output statements; control structures (conditional statements, loop control statements, break, Continue and pass).

Unit III: Functions **(10 Hours)**
Introduction to Functions and its definition: Modules, built in and user-defined functions, passing arguments and returning values, default arguments, functions as data.

Unit IV: Data Structures **(10 Hours)**
Data Structures like; Strings, Lists, Tuples, Sets, Dictionaries, Analysing their functions and basic operations.

Unit V: Advance Libraries **(13 Hours)**
Introduction to Core Libraries in Python : Numpy Library for Arrays (Creating and accessing One and Multi-Dimensional Array), Pandas Library for Data Processing (Basics of DataFrame), Matplotlib Library for Visualization (Pie Chart, Scatter Plot, Histogram, Bar Chart)

Practical component (if any) – **(30 Hours)**

- Write a program to enter a name and display: "Hello, Name".
- Write a program to compute the roots of a quadratic equation.
- Write a program to print a pyramid **pattern** with 8 rows.
- Write a menu driven program to enter a number and print whether the number is odd or even.
- Write a program to build a **random number generator** that generates random numbers between 1 and 6 (simulates a dice).
- Write a program that takes two **lists** and returns "True" if they have at least one common member.
- Write a program to check if one **list** is reverse of another.
- Write a program to check if a given **array** is Monotonic.
- Write a program to find the maximum number out of 3 entered numbers. **(loop)**
- Write a program to build a menu driven **calculator** and perform basic arithmetic operations between two numbers. (Addition, Subtraction, Multiplication and Division)
- Write a program to create a **dictionary** and remove one key.
- Write a program to enter 5 subject's marks and print the grades A/B/C/D. **(loop)**
- Write a program to print a Fibonacci sequence. **(loop)**
- Write a program in python to plot a **graph** for the function $y = x^2$.
- Programmes related to creating and modifying List, Tuple and Dictionary.
- Programmes to find correlation between dependent and independent variables.
- Programme to develop a regression model on an existing data set.
- Programmes for data visualization (Charts using plot() function, Pie Chart, Scatter Plot, Histogram, Bar Chart)
- Solution to deterministic EOQ based models for Inventory Management

Essential/recommended readings

- Deitel, P. J. (2019). P*ython Fundamentals*. Pearson.

- Dierbach, C. (2012). *Introduction to computer science using python: a computational problem-solving focus.* Wiley Publishing.
- Guttag, J. V. (2013). *Introduction to computation and programming using Python*. MIT Press.
- Lambert, K. A. (2018*). Fundamentals of python: first programs*. Cengage Learning.
- Lutz, M., & Lutz, M. (1996). *Programming python* (volume 8). O'Reilly Media, Inc.
- Thareja, R. (2017). *Python programming using problem solving approach*. Oxford University Press.
- VanderPlas, J. (2016). *Python data science handbook: essential tools for working with data.* O'Reilly Media, Inc.

Suggestive readings:: NIL

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

Category III

(B.A Programme with Operational Research as non-Major or Minor discipline)

DISCIPLINE SPECIFIC CORE COURSE – 3: Mathematical Modelling for Business

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Mathematical Modelling for Business (DSC-3)	4	3	0	1	Passed 12th class with Mathematics	Linear Programming

Learning Objectives

To acquaint students with different mathematical modelling techniques applicable in various businesses viz., inventory control, marketing management, and network flow analysis.

Learning outcomes

On successful completion of the course, students will be able to:

- Explain the meaning of Inventory control, its various forms, and the functional role of Inventory.
- Calculate the Economic Order Quantity (EOQ) for various Deterministic Inventory models.
- Comprehend inventory models with All Units Quantity Discounts
- Gain an understanding of the basic concepts and issues in marketing and their application in business decisions.
- Gain an understanding of network analysis and related mathematical models.
- Use standard methodologies for solving network flow problems.

SYLLABUS OF DSC-5

Unit I: Introduction to Inventory Management (18 Hours)

Concept and significance of inventory management, Different types of costs in the inventory system. Deterministic continuous review models: Economic order quantity (EOQ) model with and without shortages, Finite replenishment rate Inventory models without and with planned shortages. Determination of reorder point for all the models. Inventory models with All Units Quantity Discounts.

Unit II: Fundamentals for Marketing Management **(15 Hours)**

Nature, Scope, and Importance of Marketing, Basic concepts, Marketing Environment, Consumer Behaviour, Market Classification based on Competitive Conditions, Product Mix, Pricing Strategies, Media allocation for advertisement, Brand switching analysis, Concept of Measurement of Elasticity of Demand, Factors Affecting Elasticity of Demand, Income Elasticity of Demand, Cross Elasticity of Demand, Advertising Elasticity of Demand.

Unit III: Network Analysis **(12 Hours)**

Understanding of network components, Construction of network diagram, Introduction to Network flow problems and their applications: Shortest path problem, Travelling salesman problem, minimum spanning tree.

Practical component (if any) - **(30 Hours)**

Practical/Lab to be performed on a computer using OR/Statistical packages

- To find optimal inventory policy for deterministic inventory models without shortages.
- To find optimal inventory policy for deterministic inventory models without shortages.
- To solve all units quantity discounts model.
- Finding shortest path in a network.
- Solving a travelling salesman problem.
- Finding minimum spanning tree in a network.
- Problems based on media allocation for advertisement.
- Problems based on Brand switching analysis.

Essential/recommended readings

- Bazaraa, M. S., Jarvis, J. J., & Sherali, H. D. (2011). Linear programming and network flows. John Wiley & Sons.
- Hadley, G., & Whitin, T. M. (1963). *Analysis of inventory systems*. Prentice-Hall.
- Waters, D. (2008). *Inventory control and management.* (2nd Edition). John Wiley & Sons.
- Kotler P., & Keller, K. L. (2008), *Marketing management* (13th ed.). New Delhi: Pearson Education, Ltd.

Suggestive readings: Nil

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

Category IV

BSc. Physical Sciences/ Mathematical Sciences with Operational Research as one of the three Core Disciplines

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

DISCIPLINE SPECIFIC CORE COURSE – 3: MATHEMATICAL MODELLING FOR BUSINESS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Mathematical Modelling for Business (DSC-3)	4	3	0	1	Passed 12th class with Mathematics	Linear Programming

Learning Objectives

To acquaint students with different mathematical modelling techniques applicable in various businesses viz., inventory control, marketing management, and network flow analysis.

Learning outcomes

On successful completion of the course, students will be able to:

- Explain the meaning of Inventory control, its various forms, and the functional role of Inventory.
- Calculate the Economic Order Quantity (EOQ) for various Deterministic Inventory models.
- Comprehend inventory models with All Units Quantity Discounts
- Gain an understanding of the basic concepts and issues in marketing and their application in business decisions.
- Gain an understanding of network analysis and related mathematical models.
- Use standard methodologies for solving network flow problems.

SYLLABUS OF DSC-5

Unit I: Introduction to Inventory Management (18 Hours)

Concept and significance of inventory management, Different types of costs in the inventory system. Deterministic continuous review models: Economic order quantity (EOQ) model with and without shortages, Finite replenishment rate Inventory models without and with planned shortages. Determination of reorder point for all the models. Inventory models with All Units Quantity Discounts.

Unit II: Fundamentals for Marketing Management (15 Hours)
Nature, Scope, and Importance of Marketing, Basic concepts, Marketing Environment, Consumer Behaviour, Market Classification based on Competitive Conditions, Product Mix, Pricing Strategies, Media allocation for advertisement, Brand switching analysis, Concept of Measurement of Elasticity of Demand, Factors Affecting Elasticity of Demand, Income Elasticity of Demand, Cross Elasticity of Demand, Advertising Elasticity of Demand.

Unit III: Network Analysis (12 Hours)
Understanding of network components, Construction of network diagram, Introduction to Network flow problems and their applications: Shortest path problem, Travelling salesman problem, minimum spanning tree.

Practical component (if any) - (30 Hours)
Practical/Lab to be performed on a computer using OR/Statistical packages

- To find optimal inventory policy for deterministic inventory models without shortages.
- To find optimal inventory policy for deterministic inventory models without shortages.
- To solve all units quantity discounts model.
- Finding shortest path in a network.
- Solving a travelling salesman problem.
- Finding minimum spanning tree in a network.
- Problems based on media allocation for advertisement.
- Problems based on Brand switching analysis.

Essential/recommended readings

- Bazaraa, M. S., Jarvis, J. J., & Sherali, H. D. (2011). Linear programming and network flows. John Wiley & Sons.
- Hadley, G., & Whitin, T. M. (1963). *Analysis of inventory systems*. Prentice-Hall.
- Waters, D. (2008). *Inventory control and management.* (2nd Edition). John Wiley & Sons.
- Kotler P., & Keller, K. L. (2008), *Marketing management* (13th ed.). New Delhi: Pearson Education, Ltd.

Suggestive readings: Nil

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

CATEGORY-V (a)

COMMON POOL OF DISCIPLINE SPECIFIC ELECTIVES (DSE) COURSES

BSc. Physical Sciences/ Mathematical Sciences with Operational Research as one of the three Core Disciplines

DISCIPLINE SPECIFIC ELECTIVE (DSE): SIMULATION MODELLING & APPLICATIONS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Simulation Modelling and Applications (DSE-1(a))	4	3	0	1	Passed 12th class with Mathematics	Probability and Statistics

Learning Objectives

The Learning Objectives of this course are as follows:

- To acquaint students with the fundamentals of Simulation modelling
- Develop the students' analytical skills
- Introduce simulation techniques applicable in different situations

Learning outcomes

On successful completion of the course, students will be able to:

- Know the basics of simulation modelling and its scope.
- Gain knowledge of Event Type Simulation and its applications in real life.
- Understand the various methods of random number generation.
- Understand and use Monte Carlo Simulation.
- Apply Simulation Technique in Inventory Control, Queuing Systems.
- Use Simulation in Finance and Investment, Maintenance Problems and Networks.

SYLLABUS OF DSE-1(a)

Unit I: Introduction to Simulation (18 Hours)

What is Simulation, Process of Simulation, Advantages and Limitations of Simulation, Classification of Simulation Models, Continuous Event Type Simulation, Discrete Event Simulation: Components and Organization, Application of discrete event simulation in single server queueing system, inventory model and insurance risk model.

Unit II : Random Number Generation (12 Hours)

Pseudo Random Number Generators – Mixed Congruence Method, Multiplicative Congruential Method, Additive Congruential Method, the inverse transform method, Discrete and Continuous Distributions, Box Muller Method.

Unit III: Applications in Inventory and Queuing (9 Hours)

Monte Carlo Simulation, Application of Simulation in Inventory Control, Simulation of Queueing Systems.

Unit IV: Applications in Project Management (6 Hours)

Simulation of Maintenance Problems, Applications of Simulation in Finance and Investment, Simulation of Job Sequencing, Simulation of Networks.

Practical component (if any) – (30 Hours)

Practical/Lab to be performed on a computer using OR/Statistical packages

- Modelling randomness in Excel: Pseudo Random Number generators
- Generation of U (0,1)
- Simulating M/M/1 Queues
- Monte Carlo Simulation
- Simulation in Inventory Control
- Forecasting using Simulation
- Simulation in Queueing System using Monte Carlo Simulation
- Simulation in Finance and Investment

Essential/recommended readings

- Fishman, G.S. (1996). *Monte Carlo-Concepts, Algorithms and Applications*, Springer
- Taha, H.A. (2018), *Operations Research, An Introduction, 10h Edition*, Pearson.
- Sheldon M. Ross (2008), *Simulation, 4thEd*, Elsevier.
- Averill M. Law and W. David Kelton (2003), *Simulation Modeling and Analysis*, 3rd Ed., Tata McGraw-Hill.

Suggestive readings: Nil

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE (DSE):
PRODUCTION AND OPERATIONS MANAGEMENT

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Production and Operations Management (DSE-1(b))	**4**	**3**	**1**	**0**	**Passed 12th class with Mathematics**	**Nil**

Learning Objectives

The Learning Objectives of this course are as follows:

- To make students understand the strategic significance of Production and Operations Management in service and manufacturing organizations.
- To acquaint them with fundamental concepts, functions and applications of discipline, so as to deal with different types of problems faced by operations managers, and common decision-making approaches.

Learning Outcomes

On successful completion of the course, students will be able to:

- Gain an understanding of basic concepts of Production and Operations management and differentiate between them.
- Analyse the factors affecting Facility Capacity, Location, and Layout.
- Understand the Production planning and Material Requirement Planning techniques.
- Comprehend basic concepts in Just in time (JIT) Manufacturing System, Operations scheduling and Quality management.

SYLLABUS

Unit I: Introduction to Production and Operations Management (POM) (6 Hours)
Overview of Production System, Objectives of Operations Management, Scope of Operations Management, Types of Production Systems, Production Design Process and Process choices. Framework for Managing Operations; Strategic Operations Management.

Unit II: Facility Location, Layout and Capacity (12 Hours)
Factors Influencing Plant Location, Single Facility Location Problem, Multi Facility Location Problem, Models for Facility Location Problem. Facility Layout decision- importance and benefits of layout planning, different types of layouts. Capacity Planning – Measures of capacity, factors affecting demand forecasting and capacity planning, short and long-term capacity planning.

Unit III: Production Planning (12 Hours)
Aggregate planning, Master Production Schedule. Introduction to MRP and MRP II. Lot sizing in MRP systems – Lot for lot method, economic quantity method, periodic order quantity method, part period balancing, Wagner – Whitin approach. Introduction to modern productivity techniques – Just in Time (JIT), Kanban system. Inventory Control – basic concepts, Classification of Inventory System, EOQ Model.

Unit IV: Operations Scheduling and Quality Management (15 Hours)
Flow Shop Scheduling- Introduction, Single Machine Scheduling, n jobs m machines, Johnsons' rule. Quality Management: Introduction, Statistical process control, control charts, Total Quality Management (TQM), Six sigma, ISO 9000 and other ISO series.

Practical component (if any) –Nil

Essential/recommended readings

- Bedi, K. (2013). *Production & Operations Management.* 3rd edition. Oxford University Press.
- Everett E. Adam, Ronald J Ebert (1995). *Production and Operations Management: Concepts, Models, and Behavior*. Fifth edition. PHI Learning Pvt. Ltd
- Gaither, N., & Frazier, G. (2002). *Operations management*. South-Western/Thomson Learning.
- Heizer,J., Render, B., Munson, C., & Sachan, A. (2017). *Operations Management*. Twelfth edition. Pearson Education.

Suggestive readings:

Nil

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE : BUSINESS FORECASTING

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Business Forecasting	4	3	0	1	Passed 12th class with Mathematics	Probability and Statistics

Learning Objectives

The objective of this course is to introduce both managerial and technical aspects of business forecasting to students and expose them to its practical applications.
The Learning Objectives of this course are as follows:

- To introduce both managerial aspect of business forecasting
- Develop the students' ability to understand the technical aspect for business forecasting and its applications
- Introduce various forecasting techniques helpful for better decision making

Learning outcomes

On successful completion of the course, students will be able to:
- Gain an understanding of key concepts of Business Forecasting and its applications.
- Develop analytical methodologies that make prediction of future events of interest to business and industry.
- Make well-informed decisions that require forecasting of relevant variables.
- Identify relevant information to support model selection in scenarios where issues of time series analysis are involved.
- Predict relationships among business and economic variables for supporting short-term and long-term planning.

SYLLABUS OF DSE-1(c)

Unit I: Introduction **(12 Hours)**
Introduction to Business Forecasting, Importance of forecasting, Different types of forecasting methods, Identification of appropriate technique for forecasting, Applications of forecasting methods in industry, Practical issues in forecasting.

Unit II: Time Series Modeling **(15 Hours)**
Time series and its components, modelling and forecasting trend, modelling and forecasting seasonality, characterising cycles in times series, forecasting cycles, Forecasting models with trend seasonality and cycle.

Unit III: Regression Modeling **(9 Hours)**
Simple linear regression and multiple linear regression models and their applications in business.

Unit IV: Some Related Concepts **(9 Hours)**
Stationary and non-stationary time series, Autoregressive (AR) Forecasting model, Moving average (MA) model, Autoregressive moving average model (ARMA), Autoregressive integrated moving average (ARIMA) model, Random walk model. Applications of these models in business.

Practical component (if any) – **(30 Hours)**
Practical/Lab to be performed on a computer using OR/Statistical packages

- Plot and visualize time series data.
- Fitting of trend by using Method of semi averages.
- Fitting of trend by Moving Average Method.
- Measurement of Seasonal indices using method of simple average.
- Measurement of Seasonal indices using Ratio-to-Trend method.
- Measurement of Seasonal indices using Ratio-to-Moving Average method.
- Measurement of seasonal indices using Link Relative method.
- To find cyclical variations using percentage of trend method and relative cyclical residual method.
- Fitting a simple linear regression model for forecasting.
- Fitting a multiple linear regression model for forecasting.

Essential/recommended readings

- Makridakis, S., Wheelwright, S. C., & Hyndman, R. J. (2008). *Forecasting methods and applications*. John wiley & sons.
- Pindyck, R. S., & Rubinfeld, D. L. (1976). *Econometric models and economic forecasts*. McGraw-Hill.
- Butler, W. F., Kavesh, R. A., & Platt, R. B. (Eds.). (1974). *Methods and techniques of business forecasting*. Prentice Hall.
- Diebold, F. X. (2004). *Elements of Forecasting*. Thompson: South Western. Ohio, USA.

Suggestive readings

- Hanke, J. E., & Wichern, D.W. (2014). *Business Forecasting.* Pearson.
- Gujarati, D. N. (2004). *Basic econometrics. (4th ed.),* McGraw-Hill.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

CATEGORY-V (b)

COMMON POOL OF DISCIPLINE SPECIFIC ELECTIVES (DSE) COURSES

BSc(Hons.) Operational Research

DISCIPLINE SPECIFIC ELECTIVE (DSE): SIMULATION MODELLING & APPLICATIONS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Simulation Modelling and Applications (DSE-1(a))	4	3	0	1	Passed 12th class with Mathematics	Probability and Statistics

Learning Objectives

The Learning Objectives of this course are as follows:

- To acquaint students with the fundamentals of Simulation modelling
- Develop the students' analytical skills
- Introduce simulation techniques applicable in different situations

Learning outcomes

On successful completion of the course, students will be able to:

- Know the basics of simulation modelling and its scope.
- Gain knowledge of Event Type Simulation and its applications in real life.
- Understand the various methods of random number generation.
- Understand and use Monte Carlo Simulation.
- Apply Simulation Technique in Inventory Control, Queuing Systems.
- Use Simulation in Finance and Investment, Maintenance Problems and Networks.

SYLLABUS

Unit I: Introduction to Simulation (18 Hours)
What is Simulation, Process of Simulation, Advantages and Limitations of Simulation, Classification of Simulation Models, Continuous Event Type Simulation, Discrete Event Simulation: Components and Organization, Application of discrete event simulation in single server queueing system, inventory model and insurance risk model.

Unit II : Random Number Generation (12 Hours)
Pseudo Random Number Generators – Mixed Congruence Method, Multiplicative Congruential Method, Additive Congruential Method, the inverse transform method, Discrete and Continuous Distributions, Box Muller Method.

Unit III: Applications in Inventory and Queuing (9 Hours)
Monte Carlo Simulation, Application of Simulation in Inventory Control, Simulation of Queueing Systems.

Unit IV: Applications in Project Management (6 Hours)
Simulation of Maintenance Problems, Applications of Simulation in Finance and Investment, Simulation of Job Sequencing, Simulation of Networks.

Practical component (if any) – (30 Hours)
Practical/Lab to be performed on a computer using OR/Statistical packages

- Modelling randomness in Excel: Pseudo Random Number generators
- Generation of U (0,1)
- Simulating M/M/1 Queues
- Monte Carlo Simulation
- Simulation in Inventory Control
- Forecasting using Simulation
- Simulation in Queueing System using Monte Carlo Simulation
- Simulation in Finance and Investment

Essential/recommended readings

- Fishman, G.S. (1996). *Monte Carlo-Concepts, Algorithms and Applications*, Springer
- Taha, H.A. (2018), *Operations Research, An Introduction, 10h Edition*, Pearson.
- Sheldon M. Ross (2008), *Simulation, 4thEd*, Elsevier.
- Averill M. Law and W. David Kelton (2003), *Simulation Modeling and Analysis*, 3rd Ed., Tata McGraw-Hill.

Suggestive readings: Nil

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE (DSE):
Numerical Analysis

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Numerical Analysis (DSE-1(b))	4	3	0	1	12th class with Mathematics	Nil

Learning Objectives

The Learning Objectives of this course are as follows:

- To acquaint students with the techniques that uses algorithms for approximation problems.
- Develop the students' ability to use various numerical method techniques
- To make the students formulate and apply appropriate strategy to solve real world problems.

Learning outcomes

On successful completion of the course, students will be able to:

- Know the basic elements of numerical methods and error analysis
- Learn Iterative methods for finding the roots of the algebraic and transcendental equations
- Apply the numerical methods to solve system of linear equations and understand the methods convergence analysis.
- Understand the concepts of finite differences, derive the interpolation formulae and understand its applications.

SYLLABUS OF DSE-1(b)

Unit I **(12 Hours)**

Errors: Relative Error, Absolute Error, Round off Error, Truncation Error. Transcendental and Polynomial equations: Bisection method, Newton-Raphson method, Secant method. Method of False Position, Fixed point iterative method, Order and rate of convergence of these methods.

Unit II **(9 Hours)**

System of linear equations: Gauss Elimination and Gauss Jordan methods. Gauss Jacobi method, Gauss Seidel method and their convergence analysis.

Unit III **(9 Hours)**
Interpolation: Lagrange Interpolating Polynomial, Newton's Gregory forward and backward difference interpolating polynomial, Newton's Divided Difference Interpolating Polynomial, Error analysis in each method.

Unit IV **(15 Hours)**
Numerical Integration: Trapezoidal rule, Composite Trapezoidal rule, Simpson's rule, Composite Simpson's rule, Simpsons 3/8th rule. Ordinary Differential Equations: Euler's method, Modified Euler's method, Runge-Kutta method

Practical component (if any) – **(30 Hours)**
Practical/Lab to be performed on a computer using OR/Statistical packages for developing the following numerical programs:

1. Bisection method
2. Newton Raphson method
3. Secant method
4. Regula Falsi method
5. LU decomposition method
6. Gauss-Jacobi method
7. Gauss-Seidel method
8. Lagrange interpolation
9. Newton interpolation
10. Trapezoidal rule
11. Simpson's rule
12. Euler's method

Essential/recommended readings

- Sastry, S. S. (2012). *Introductory methods of numerical analysis*. PHI Learning Pvt. Ltd..
- Gerald, C. F., & Wheatley, P. O. (2008). *Applied Numerical Analysis (7th ed.).* Pearson Education. India.
- Bradie, Brian. (2006). *A Friendly Introduction to Numerical Analysis*. Pearson Education, India. Dorling Kindersley (India) Pvt. Ltd. Third impression 2011.
- Mudge, M. R. (2003). *An introduction to numerical methods and analysis*,(Wiley).

Suggestive readings:

- Jain, M. K., Iyengar, S. R. K., & Jain, R. K. (2012). *Numerical Methods for Scientific and Engineering Computation. (6th ed.).* New Age International Publisher, India, 2016.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE (DSE): BUSINESS FORECASTING

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Business Forecasting	4	3	0	1	Passed 12th class with Mathematics	Probability and Statistics

Learning Objectives

The objective of this course is to introduce both managerial and technical aspects of business forecasting to students and expose them to its practical applications.
The Learning Objectives of this course are as follows:

- To introduce both managerial aspect of business forecasting
- Develop the students' ability to understand the technical aspect for business forecasting and its applications
- Introduce various forecasting techniques helpful for better decision making

Learning outcomes

On successful completion of the course, students will be able to:

- Gain an understanding of key concepts of Business Forecasting and its applications.
- Develop analytical methodologies that make prediction of future events of interest to business and industry.
- Make well-informed decisions that require forecasting of relevant variables.
- Identify relevant information to support model selection in scenarios where issues of time series analysis are involved.
- Predict relationships among business and economic variables for supporting short-term and long-term planning.

SYLLABUS OF DSE-1(c)

Unit I: Introduction (12 Hours)

Introduction to Business Forecasting, Importance of forecasting, Different types of forecasting methods, Identification of appropriate technique for forecasting, Applications of forecasting methods in industry, Practical issues in forecasting.

Unit II: Time Series Modeling **(15 Hours)**
Time series and its components, modelling and forecasting trend, modelling and forecasting seasonality, characterising cycles in times series, forecasting cycles, Forecasting models with trend seasonality and cycle.

Unit III: Regression Modeling **(9 Hours)**
Simple linear regression and multiple linear regression models and their applications in business.

Unit IV: Some Related Concepts **(9 Hours)**
Stationary and non-stationary time series, Autoregressive (AR) Forecasting model, Moving average (MA) model, Autoregressive moving average model (ARMA), Autoregressive integrated moving average (ARIMA) model, Random walk model. Applications of these models in business.

Practical component (if any) – **(30 Hours)**
Practical/Lab to be performed on a computer using OR/Statistical packages

- Plot and visualize time series data.
- Fitting of trend by using Method of semi averages.
- Fitting of trend by Moving Average Method.
- Measurement of Seasonal indices using method of simple average.
- Measurement of Seasonal indices using Ratio-to-Trend method.
- Measurement of Seasonal indices using Ratio-to-Moving Average method.
- Measurement of seasonal indices using Link Relative method.
- To find cyclical variations using percentage of trend method and relative cyclical residual method.
- Fitting a simple linear regression model for forecasting.
- Fitting a multiple linear regression model for forecasting.

Essential/recommended readings

- Makridakis, S., Wheelwright, S. C., & Hyndman, R. J. (2008). *Forecasting methods and applications*. John wiley & sons.
- Pindyck, R. S., & Rubinfeld, D. L. (1976). *Econometric models and economic forecasts*. McGraw-Hill.
- Butler, W. F., Kavesh, R. A., & Platt, R. B. (Eds.). (1974). *Methods and techniques of business forecasting*. Prentice Hall.
- Diebold, F. X. (2004). *Elements of Forecasting*. Thompson: South Western. Ohio, USA.

Suggestive readings

- Hanke, J. E., & Wichern, D.W. (2014). *Business Forecasting.* Pearson.
- Gujarati, D. N. (2004). *Basic econometrics. (4th ed.),* McGraw-Hill.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

CATEGORY-VI

COMMON POOL OF GENERIC ELECTIVES (GE) COURSES

GENERIC ELECTIVES (GE): QUEUING AND RELIABILITY THEORY

Credit distribution, Eligibility and Pre-requisites of the Course

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course
		Lecture	Tutorial	Practical/ Practice		
Queuing and Reliability Theory	4	3	0	1	Passed 12th class with Mathematics	Probability and Statistics

Learning Objectives

The Learning Objectives of this course are as follows:

- To make students understand the basic idea of random variables and their associated probability distributions as it is a prerequisite.
- To enrich students with the concept of stochastic processes and its applications in the field of queuing theory.
- To make students learn the mathematical theory of queuing systems.
- To introduce students with the concept of system reliability and make them learn to evaluate reliability of various system configurations.
- To provide students hands-on experience of the queuing and reliability models through practical sessions using certain software.

Learning outcomes

On successful completion of the course, students will be able to:

- Understand the concepts and mathematical theory related to queuing systems & system reliability required to understand, analyse and solve any real-world problem.

- Learn the concepts of stochastic processes, Markov processes, Markov chains and apply these mathematical models in real-life problems.
- Evaluate the performance metrics of any queuing system.
- Compute the system reliability of any type of system-configuration.
- Make use of software for problem analysis.

SYLLABUS

Unit I : Basic characteristics of a queueing system (12 Hours)
Kendall's notation, performance measures of a queueing system, Little's formula, Traffic intensity, Some general results for G/G/1 and G/G/c queueing models, Introduction to stochastic processes, Markov chain and Markov process, pure-birth process, pure-death process, birth-death process.

Unit II: Markovian queuing models (15 Hours)
single & multiple servers, finite & infinite system capacity, and finite & infinite population size, Cost analysis, Applications of queuing theory.

Unit III: Basic tools of Reliability (9 Hours)
Reliability function, and related concepts like hazard rate, mean time to failure (MTTF), classes of lifetime distributions, and hazard rate of Exponential and Weibull distributions.

Unit IV: System Reliability (9 Hours)
Reliability, hazard rate and MTTF of various system configurations- series, parallel, mixed configuration, k out of n system and stand-by system.

Practical component (if any) – (30 Hours)
Practical/Lab to be performed on a computer using OR/Statistical packages
- Finding measures of performance for deterministic queuing system.
- Finding measures of performance for M/M/1 queuing system with infinite capacity.
- Finding measures of performance for M/M/1 queuing system with finite capacity.
- Finding measures of performance for M/M/c queuing system with infinite capacity.
- Finding measures of performance for M/M/c queuing system with finite capacity.
- Finding measures of performance for any Markovian queuing system with multiple servers and with finite/infinite capacity.
- Measuring reliability of different types of system configuration.
- Measuring reliability, hazard rate and MTTF of different types of system configuration.

Essential/recommended readings

- Medhi J. (2009), *Stochastic Processes* (3rd Edition), New Delhi: New age science Ltd.
- Gross D., Shortle J. F, Thompson J. M., & Harris C. M. (2008), *Fundamentals of Queuing Theory* (4th edition), New Jersey: John Wiley & Sons, inc.
- Trivedi K. S. (2016), *Probability & Statistics with Reliability, Queuing & Computer Science applications*, New Jersey: John Wiley & Sons, Inc
- Srinath L. S., (2005), *Reliability Engineering*, New Delhi, East West Press.
- Rausand M. & Hoyland A. (2003), *System Reliability Theory: Models, Statistical Methods & Applications* (2nd ed.), New Jersey, John Wiley & Sons, Inc.

- Hiller F. S., Lieberman G. J., Nag B., Basu P. (2017). *Introduction to Operations Research- Concepts & Cases* (10th edition), New Delhi, Tata McGraw-Hill (Indian Print).
- Taha, H. A. (2019). *Operations Research-An Introduction* (10th ed.). New Delhi: Pearson Prentice Hall (Indian print).

Suggestive readings-Nil

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DEPARTMENT OF STATISTICS
B. Sc. (H) Statistics
Category-I

DISCIPLINE SPECIFIC CORE COURSE-7: SAMPLE SURVEYS

CREDIT DISTRIBUTION, ELIGIBILITY, AND PRE-REQUISITES OF THE COURSE

Course title & code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Sample Surveys	4	3	0	1	Passed Class XII with Mathematics	Descriptive Statistics and probability theory

Learning Objectives:
The learning objectives of this course are to introduce:
- Tools and techniques for selecting a representative sample from a target population keeping in mind the objectives to be fulfilled.
- Obtain an estimator of the population parameter on the basis of the selected sample and study its properties.

Learning Outcomes:
After successful completion of this course, students should be able to:
- Understand the fundamental concepts of population and sample and the principles of sample survey
- Describe the value and methodologies for sample surveys versus other approaches to collecting information from populations.
- Determine the appropriate sample size and its allocation for nationwide sample surveys or for surveys to be conducted in a program area.
- Identify a proper sampling frame and select primary sample points.
- Apply steps involved in selecting a sample using Simple Random Sampling with or without replacement, Stratified Sampling, Systematic Sampling and Ratio and Regression Methods of Estimation

SYLLABUS OF DSC-7
Theory

UNIT I **(10 Hours)**

Basics of Survey Sampling

Concept of population and sample, complete enumeration versus sampling, sampling and non-sampling errors. Types of sampling: non-probability and probability sampling, basic principles of sample survey, Steps involved in survey sampling.

UNIT II **(8 Hours)**

Simple Random Sampling

Simple random sampling (SRS) with and without replacement, their properties, procedures of selecting a simple random sample, estimation of population mean and total, sampling for proportions, determination of sample size, bivariate population.

UNIT III **(10 Hours)**

Stratified Random Sampling

Stratified Random Sampling: Estimation of population mean and total, Allocation of sample in different strata using equal, proportional, optimum and Neyman allocations, comparison with SRS, practical difficulties in adopting Neyman allocation, estimation of gain in precision due to stratification.

UNIT IV **(7 Hours)**

Systematic Random Sampling

Systematic Random Sampling: Estimation of population mean and total, comparison with SRS and stratified sampling in the presence of linear trend, Yates' correction, definition of circular systematic sampling.

UNIT V **(10 Hours)**

Ratio and Regression Method of Estimation

Ratio method of estimation, first approximation to ratio estimator and its bias, first approximation to variance of ratio estimator, estimator of variance of ratio estimator, comparison of ratio with SRS.

Regression method of estimation, first approximation to linear regression estimator and its bias, first approximation to variance of the linear regression estimator, estimator of variance of the linear regression estimator, comparison with SRS and ratio estimator.

Practical -30 Hours

List of Practicals :

1. To select SRS with and without replacement.
2. For a population of size 5, estimate population mean, population mean square and population variance. Enumerate all possible samples of size 2 by WR and establish all properties relative to SRS.
3. For a population of size 5, estimate population mean, population mean square and population variance. Enumerate all possible samples of size 2 by WOR and establish all properties relative to SRS.
4. Estimate mean, standard error and the sample size for SRSWOR.
5. Stratified Sampling: allocation of sample to strata by proportional. Compare the efficiencies of above method relative to SRS.
6. Stratified Sampling: allocation of sample to strata by Neyman's methods. Compare the efficiencies of above method relative to SRS.
7. Estimation of gain in precision in stratified sampling.
8. Comparison of systematic sampling with stratified sampling and SRS in the presence of a linear trend and using end's correction.
9. Ratio estimation: Calculate the population mean or total of the population. Calculate mean squares. Compare the efficiency of ratio estimator relative to SRS.
10. Regression estimation: Calculate the population mean or total of the population.
11. Calculate mean squares. Compare the efficiency of regression estimator relative to SRS.

Practical work to be conducted using electronic spreadsheet / EXCEL/ Statistical Software Package/ SPSS/ calculators.

ESSENTIAL READINGS

- Goon A M, Gupta M K and Dasgupta B (2018): Fundamentals of Statistics, Volume II, 9^{th} Edition and 4^{th} reprint.
- Cochran, W.G. (2011): Sampling Techniques (3^{rd} Ed.), Wiley Eastern John Wiley and Sons.
- Sukhatme, P. V., Sukhatme, B. V., Sukhatme, S., Asok, C.(1984). Sampling Theories of Survey with Application, IOWA State University Press and Indian Society of Agricultural Statistics.

SUGGESTIVE READINGS:

- Gupta, S.C. and Kapoor, V.K. (2007): Fundamentals of Applied Statistics, Sultan Chand and Sons.
- Singh, D. and Chaudhary, F. S. (2015): Theory and Analysis of Sample Survey Designs.
- Murthy M.N. (1977): Sampling Theory & Statistical Methods, Statistical Pub. Society, Calcutta.
- Des Raj and Chandhok P. (1998): Sample Survey Theory, Narosa Publishing House.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE-8: ADVANCED PROBABILITY DISTRIBUTIONS

CREDIT DISTRIBUTION, ELIGIBILITY, AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the Course			Eligibility Criteria	Pre-requisite of the Course (if any)
		Lecture	Tutorial	Practical/ Practice		
Advanced Probability Distributions	4	3	0	1	Passed Class XII with Mathematics	Theory of probability distributions

Learning Objectives

The learning objectives of this course are as follows:

- The course introduces students to advanced discrete and continuous probability distributions, and their important characteristics.
- It will enable them to understand the applications of these distributions.

Learning Outcomes

After successful completion of this course, students should be able to:

- Understand important advanced discrete probability distributions and their properties.
- Understand and apply important advanced continuous probability distributions and their properties.
- Apply their understanding of these distributions in real-life problems related to different areas of statistics.

SYLLABUS OF DSC-8

Theory

UNIT I **(15 hours)**

Discrete Probability Distributions

Negative Binomial Distribution: Probability distribution, particular cases, moment generating function, cumulants, limiting case, derivation of moments from binomial distribution and recurrence relation for probabilities of negative binomial distribution. Examples and applications based on the distribution. Hypergeometric Distribution: Probability distribution, mean, variance, approximation to Binomial Distribution and recurrence relation. Examples and applications based on the distribution. Geometric Distribution: Probability distribution, lack of memory property, moments and moment generating function. Examples and applications based on the distribution. Multinomial Distribution: Probability distribution and practical application.

UNIT II **(15 hours)**

Continuous Probability Distributions

Rectangular or Uniform Distribution: Definition, probability distribution and cumulative probability distribution, moments, and moment generating function, characteristic function and mean deviation about mean. Examples and applications based on the distribution. Gamma Distribution: Definition and properties, probability distribution, mean, variance, moment generating function, cumulant generating function, additive property and limiting case. Examples and applications based on the distribution. Beta Distribution: Beta Distribution of the first kind: Definition, probability distribution and cumulative probability distribution, mean, variance and harmonic mean. Beta Distribution of the second kind: Definition, probability distribution, mean, variance and harmonic mean. Examples and applications based on the distributions.

UNIT III **(15 hours)**

Continuous Probability Distributions (contd.)

Exponential Distribution: Definition, probability distribution and cumulative probability distribution, moment generating function, mean, variance and lack of memory property. Examples and applications based on the distribution. Standard Laplace (Double Exponential) Distribution: Definition, probability distribution, characteristic function and moments. Two Parameter Laplace Distribution: Definition, probability distribution, characteristic function and moments. Examples and applications based on the distribution. Weibull Distribution: Probability distribution, moments and practical applications. Logistic Distributions: Probability distribution, moments and practical applications. Cauchy Distribution: Definition, probability distribution, characteristics function, additive property and moments. Examples and applications based on the distribution.

PRACTICAL – 30 Hours

List of Practicals:

Practicals based on:

1. Application of Negative Binomial Distribution.

2. Fitting of Negative Binomial Distribution.
3. Application of Hypergeometric Distribution
4. Fitting of Geometric Distribution.
5. Lack of memory property of Geometric Distribution
6. Applications of
   (a) Geometric Distribution.
   (b) Multinomial Distribution.
   (c) Rectangular Distribution
   (d) Gamma Distribution
   (e) Beta Distribution.
   (f) Exponential Distribution.
   (g) Weibull Distribution.
   (h) Logistic Distribution.
   (i) Cauchy Distribution.
7. Lack of memory property of Exponential Distribution.

Practical work to be conducted using electronic spreadsheet / EXCEL/ Statistical Software Package/ SPSS.

ESSENTIAL READINGS

- Gupta, S. C. and Kapoor, V. K. (2020). Fundamentals of Mathematical Statistics, Twelfth Edition, Sultan Chand and Sons, Delhi.
- Ross, Sheldon M. (2013): A First Course in Probability, Ninth Edition, Pearson.
- Miller, I. and Miller, M. (2006). John E. Freund's Mathematical Statistics with Applications, Eight Edition., Pearson Education, Asia.
- Mood, A.M. Graybill, F.A. and Boes, D.C. (2007). Introduction to the Theory of Statistics, Third Edition, (Reprint), Tata McGraw-Hill Pub. Co. Ltd.

SUGGESTED READINGS

- Rohatgi, V. K and Saleh M. E. (2015). An Introduction to Probability and Statistics, Third Edition, John Wiley and Sons, Inc., New Jersey.
- Hogg, R.V., Tanis, E.A. and Rao, J.M. (2009). Probability and Statistical Inference, 7th Ed., Pearson Education, New Delhi.
- Ross, Sheldon M.(2009). Introduction to Probability and Statistics for Engineers and Scientists, Fourth Edition, Academic Press.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE – 9: MATHEMATICAL ANALYSIS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Mathematical Analysis-DSC-09	4	3	0	1	**Passed Class XII with Mathematics**	Nil

Learning Objectives

The learning objectives include:

- To study Real Analysis, which deals with the analytical properties of real functions and sequences.
- To study Numerical Analysis, which is the study of algorithms that use numerical approximation for the problems of mathematical analysis.

Learning Outcomes:

After successful completion of this course, students should be able to:

- Understand the fundamental properties of real numbers and real-valued functions.
- Understand the Analytical properties of sequences.
- Apply Infinite series, their properties and different tests.
- Apply limits, continuity, differentiability, and mean value theorems.
- Use the fundamentals of numerical analysis, interpolation, numerical integration and difference equation.

SYLLABUS OF DSC-9

Theory

UNIT I **(10 hours)**

Set Theory and Sequences

Completeness: The Completeness property of R; Archimedean property in R; Neighbourhood and limit points: Neighbourhood, Open Set, Closed Set, Supremum and Infimum, Limit Point of a Set; Sequences: Definition of a Sequence, Convergent Sequence, Divergent Sequence, Oscillatory Sequence, Cauchy Sequence, Monotone Sequence.

UNIT II **(10 hours)**

Series

Infinite series, positive termed series and their convergence, Comparison test, D'Alembert's ratio test, Cauchy's n^{th} root test, Raabe's test. Gauss test, Cauchy's condensation test and integral test (Statements and Examples only). Absolute convergence of series, Conditional convergence.

UNIT III **(10 hours)**

Limit and Continuity

Review of limit, continuity and differentiability, uniform Continuity and boundedness of a function. Rolle's and Lagrange's Mean Value theorems. Taylor's theorem with Lagrange's and Cauchy's form of remainder (without proof). Taylor's and Maclaurin's series expansions of sin(x), cos(x), log (1+x).

UNIT IV **(15 hours)**
Numerical Methods
Factorial, finite differences and interpolation. Operators, E and divided difference. Newton's forward, backward and divided differences interpolation formulae. Lagrange's interpolation formulae. Gauss and Stirling interpolation formulae. Numerical integration. Trapezoidal rule, Simpson's one-third rule, three-eights rule, Stirling's approximation to factorial n. Solution of difference equations of first order, Euler Maclaurin's summation formula.

PRACTICAL/LAB WORK – (30 hours)
List of Practical:
Practicals based on:
1. Formation of difference table, fitting of polynomial and missing terms for equal interval of differencing.
2. Newton's Gregory forward difference interpolation formula.
3. Newton's backward difference interpolation formula.
4. Newton's divided difference and Lagrange's interpolation formula.
5. Gauss forward, Gauss backward central difference interpolation formula.
6. Stirling's central difference interpolation formula.
7. Lagrange's Inverse interpolation formula.
8. Method of successive approximation or iteration.
9. Method of reversion of series.
10. Trapezoidal Rule, Simpson's one-third rule, Simpson's three-eighth rule, Weddle's rule.
11. Euler-Maclaurin summation formula

Practical work to be conducted using electronic spreadsheet / EXCEL/ Statistical Software Package/ SPSS/ calculators.

ESSENTIAL READINGS

- Appostol, T.M. (1987). Mathematical Analysis, 2nd Ed., Narosa Publishing House,New Delhi
- Ghorpade, S.R. and Limaye, B.V. (2006). A Course in Calculus and Real Analysis, Undergraduate Texts in Mathematics, Springer (SIE), Indian reprint.
- Sastry, S.S. (2000). Introductory Methods of Numerical Analysis, 3rd Ed., Prentice Hall of India Pvt. Ltd., New Delhi.

SUGGESTIVE READINGS:

- Bartle, R.G. and Sherbert, D.R. (2002). Introduction to Real Analysis, (3rd Ed.,), John Wiley and Sons (Asia) Pte. Ltd., Singapore.
- Jain, M.K., Iyengar, S.R.K. and Jain, R.K. (2003). Numerical methods for scientific and engineering computation, New age International Publisher, India.
- Malik, S.C. and Arora, S. (1994). Mathematical Analysis, Second Edition, Wiley Eastern Limited, New Age International Limited, New Delhi.
- Mukherjee, Kr. Kalyan (1990). Numerical Analysis. New Central Book Agency.
- Narayan, S. (1987). A course of Mathematical Analysis, 12th revised Ed., S. Chand &Co. (Pvt.) Ltd., New Delhi.

- Somasundram, D. and Chaudhary, B. (1987). A First Course in Mathematical Analysis, Narosa Publishing House, New Delhi.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch University of Delhi, from time to time.

B.SC. (P)/B.A(P) WITH STATISTICS AS MAJOR

Category II

DISCIPLINE SPECIFIC CORE COURSE – 1: SAMPLING DISTRIBUTIONS

CREDIT DISTRIBUTION, ELIGIBILITY, AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Sampling Distributions	4	3	0	1	**Passed Passed Class XII with Mathematics**	Statistical Methods

Learning Objectives:

The learning objectives include:

- To understand the concept of sampling distributions and their applications in statistical inference.
- To understand the process of hypothesis testing.
- To have a clear understanding of when to apply various tests of hypothesis about population parameters using sample statistics and draw appropriate conclusions from the analysis.

Learning Outcomes:

After successful completion of this course, students should be able to:

- Understand the basic concepts of hypothesis testing, including framing of the null and alternative hypotheses.
- Apply hypothesis testing based on a single sample and two samples using both classical and p-value approaches.
- Understand the Chi-square distribution.
- Analyze categorical data by using Chi-square techniques.
- Apply t and F distributions

SYLLABUS OF DSC-5

Theory

Unit I **(15 hours)**

Large sample tests

Large sample tests: Definitions of a random sample, parameter, and statistic, sampling distribution of a statistic, sampling distribution of the sample mean, standard errors of the sample mean, and the sample proportion. Null and alternative hypotheses, level of significance, Type I and Type II errors, their probabilities and critical region. Large sample tests, use of CLT for testing single proportion, difference of two proportions, single mean, difference of two means, standard deviation and difference of standard deviations by classical and p-value approaches.

Unit II **(15 hours)**

Chi-square distribution

Chi-square distribution: Definition and derivation of $\chi2$ distribution with n degrees of freedom (d.f.) using m.g.f., nature of probability curve for different degrees of freedom, mean, variance, m.g.f., cumulant generating function, mode, additive property and limiting form of $\chi2$ distribution. Tests of significance and confidence intervals based on χ^2 distribution.

Unit III **(15 hours)**

Exact Sampling Distributions

t and F distributions: Student's t and Fishers t-distributions, Derivation of its p.d.f., nature of probability curve with different degrees of freedom, mean, variance, moments and limiting form of t distribution. Snedecore's F-distribution: Derivation of F distribution, nature of probability curve with different degrees of freedom, mean, variance and mode. Distribution of $1/F(n_1,n_2)$. Relationship between t, F and $\chi2$ distributions. Test of significance and confidence intervals based on t and F distributions.

PRACTICAL/LAB WORK - 30 hours

List of Practicals

1. Large Sample Tests:
   a) Testing of significance and confidence intervals for single proportion and difference of two proportions.
   b) Testing of significance and confidence intervals for single mean and difference of two means.
   c) Testing of significance and confidence intervals for difference of two standard deviations.
2. Tests based on Chi-Square Distribution:
   a) To test if the population variance has a specific value and its confidence intervals.
   b) To test the goodness of fit.
   c) To test the independence of attributes.
   d) Test based on 2 x 2 contingency table without and with Yates' corrections.
3. Tests based on t- Distribution and F- Distribution:
   a) Testing of significance and confidence intervals for single mean and difference of two means and paired t – test.
   b) Testing of significance and confidence intervals of an observed sample correlation coefficient.
   c) Testing and confidence intervals of equality of two population variances.

Practical work to be conducted using electronic spreadsheet / EXCEL/ Statistical Software Package/ SPSS/ calculators.

ESSENTIAL READINGS :

● Gupta, S. C. and Kapoor, V. K. (2020). Fundamentals of Mathematical Statistics, 12^{th} Ed., S. Chand and Sons. Delhi.

● Goon A M, Gupta M K and Dasgupta B (2018): Fundamentals of Statistics, Volume II, 9^{th} Edition and 4^{th} reprint.

● Rohatgi, V. K. and Saleh, A.K. Md. E. (2009). An Introduction to Probability and Statistics, 2nd Ed., (Reprint) John Wiley and Sons.

SUGGESTIVE READINGS:

● Hogg, R.V. and Tanis, E.A. (2009). A Brief Course in Mathematical Statistics. Pearson Education.

- Mood, M.A., Graybill, F.A. and Boes, C.D. (2007). Introduction to the Theory of Statistics, 3rd Ed., (Reprint).Tata McGraw-Hill Pub. Co. Ltd.
- Johnson, R.A. and Bhattacharya, G.K. (2001). Statistics-Principles and Methods, 4th Ed., John Wiley and Sons.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE – 6: STATISTICAL QUALITY CONTROL

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Statistical Quality Control	4	3	0	1	**Passed Class XII with Mathematics**	Statistical Methods

Learning Objectives

The learning objectives include:

- This course will help students to learn techniques and approaches of SQC being used in industry to manufacture goods and services of high quality at low cost.
- This course will also give exposure to sampling inspection plans.

Learning Outcomes:

After successful completion of this course, students should be able to:

- Comprehend the concept of Statistical Quality Control and its application in Industry.
- Apply Statistical process control tools- Control charts for variables, and attributes.
- Analyse different patterns of variation on Control charts
- Apply statistical product control tools- Sampling inspection plans.

SYLLABUS OF DSC-6

Theory

UNIT I: **(9 hours)**

Basics of Quality

Definition, dimensions of quality, its concept, application, and importance. Introduction to Process and Product Control. Statistical Process Control - Seven tools of SPC, Chance and Assignable Causes of quality variation.

UNIT II: **(21 hours)**

Statistical Control Charts

Construction and Statistical basis of 3-σ Control charts, Control charts for variables: $\underline{X}$& R-chart, $\underline{X}$ & s-chart. chart (for known and unknown parameters) Control charts for attributes:

np-chart, p-chart, c-chart (for known and unknown parameters). Revised control limits. Comparison between control charts for variables and control charts for attributes. Analysis of patterns on control chart. Differentiate between Control Limits, Specification Limits and Natural Tolerance Limits. Concept of process capability.

UNIT III: (15 hours)
Acceptance sampling plan
Principle of acceptance sampling plans. Single sampling plan its OC, AQL, LTPD, AOQ, AOQL, ASN, ATI functions with graphical interpretation. Introduction to Dodge and Romig's sampling inspection plan tables.

PRACTICAL/LAB WORK - (30 hours)
List of Practical:
1. Construction and interpretation of statistical control charts for
a) $\underline{X}$ and R-chart
b) $\underline{X}$ and s-chart
c) np-chart
d) p-chart
e) c-chart
2. Single sample inspection plan: Construction and interpretation of OC, AQL, LTPD, ASN, ATI, AOQ, AOQL curves.

Practical work to be conducted using electronic spreadsheet / EXCEL/ Statistical Software Package/ SPSS/ calculators.

ESSENTIAL READINGS
- Montgomery, D. C. (2009). Introduction to Statistical Quality Control, 6th Ed., Wiley India Pvt. Ltd.
- Goon, A.M., Gupta, M.K. and Dasgupta, B. (2002). Fundamentals of Statistics, Vol. I & II, 8th Ed., The World Press, Kolkata.

SUGGESTIVE READINGS:
- Gupta, S.C. and Kapoor, V.K. (2014). Fundamentals of Mathematical Statistics, 11th Ed., Sultan Chand.
- Mukhopadhyay, P (2011): Applied Statistics, 2nd edition revised reprint, Books and Allied(P) Ltd

Note: Examination scheme and mode shall be as prescribed by the Examination Branch University of Delhi, from time to time.

B.Sc. (P)/B.A(P) with Statistics as Non-Major

Category III

DISCIPLINE SPECIFIC CORE COURSE – 3: SAMPLING DISTRIBUTIONS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Sampling Distributions	4	3	0	1	**Passed Class XII with Mathematics**	Statistical Methods

Learning Objectives:

The learning objectives include:

- To understand the concept of sampling distributions and their applications in statistical inference.
- To understand the process of hypothesis testing.
- To have a clear understanding of when to apply various tests of hypothesis about population parameters using sample statistics and draw appropriate conclusions from the analysis.

Learning Outcomes:

After successful completion of this course, students should be able to:

- Understand the basic concepts of hypothesis testing, including framing of the null and alternative hypotheses.
- Apply hypothesis testing based on a single sample and two samples using both classical and p-value approaches.
- Understand the Chi-square distribution.
- Analyze categorical data by using Chi-square techniques.
- Apply t and F distributions

SYLLABUS OF DSC-3

Theory

Unit I **(15 hours)**

Large sample tests

Large sample tests: Definitions of random sample, parameter and statistic, sampling distribution of a statistic, sampling distribution of sample mean, standard errors of sample mean, and sample proportion. Null and alternative hypotheses, level of significance, Type I and Type II errors, their probabilities and critical region. Large sample tests, use of CLT for testing single proportion, difference of two proportions, single mean, difference of two means, standard deviation and difference of standard deviations by classical and p-value approaches.

Unit II **(15 hours)**

Chi square distribution

Chi square distribution: Definition and derivation of $\chi 2$ distribution with n degrees of freedom (d.f.) using m.g.f., nature of probability curve for different degrees of freedom, mean, variance, m.g.f., cumulant generating function, mode, additive property and limiting form of $\chi2$ distribution. Tests of significance and confidence intervals based on $\chi2$ distribution.

Unit III **(15 hours)**

Exact Sampling Distributions

t and F distributions: Student's t and Fishers t-distributions, Derivation of its p.d.f., nature of probability curve with different degrees of freedom, mean, variance, moments and limiting form of t distribution. Snedecore's F-distribution: Derivation of F distribution, nature of probability curve with different degrees of freedom, mean, variance and mode. Distribution of $1/F(n_1,n_2)$. Relationship between t, F and $\chi2$ distributions. Test of significance and confidence intervals based on t and F distributions.

PRACTICAL/LAB WORK - (30 hours)

List of Practicals

1. Large Sample Tests:
(i) Testing of significance and confidence intervals for single proportion and difference of two proportions.
(ii) Testing of significance and confidence intervals for single mean and difference of two means.
(iii) Testing of significance and confidence intervals for the difference of two standard deviations.
2. Tests based on Chi-Square Distribution:
(i) To test if the population variance has a specific value and its confidence intervals.
(ii) To test the goodness of fit.
(iii) To test the independence of attributes.
(iv) Test based on 2 x 2 contingency table without and with Yates' corrections.
3. Tests based on t- Distribution and F- Distribution:
(i) Testing of significance and confidence intervals for single mean and difference of two means and paired t – test.
(ii) Testing of significance and confidence intervals of an observed sample correlation coefficient.
(iii) Testing and confidence intervals of equality of two population variances.

ESSENTIAL READINGS :

- Gupta, S. C. and Kapoor, V. K. (2020). Fundamentals of Mathematical Statistics, 12^{th} Ed., S. Chand and Sons. Delhi.
- Rohatgi, V. K. and Saleh, A.K. Md. E. (2009). An Introduction to Probability and Statistics, 2nd Ed., (Reprint) John Wiley and Sons.
- Goon, A.M., Gupta, M.K. and Dasgupta, B. (2003). An Outline of Statistical Theory, Vol. I, 4^{th} Ed., World Press, Kolkata.

SUGGESTIVE READINGS:

- Hogg, R.V. and Tanis, E.A. (2009). A Brief Course in Mathematical Statistics. Pearson Education.
- Mood, M.A., Graybill, F.A. and Boes, C.D. (2007). Introduction to the Theory of Statistics, 3rd Ed., (Reprint).Tata McGraw-Hill Pub. Co. Ltd.
- Johnson, R.A. and Bhattacharya, G.K. (2001). Statistics-Principles and Methods, 4th Ed., John Wiley and Sons.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

Discipline Specific Elective
Category-V
Discipline Specific Elective for B. Sc. (H) Statistics

DISCIPLINE SPECIFIC ELECTIVE COURSE-1A: Optimization Techniques

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Operational Research	4	3	0	1	**Passed Class XII with Mathematics**	**Nil**

Learning Objectives:

The learning objectives include:

- To create awareness about the term operational research (OR) and acquaint them with the methodologies, scope, limitations and applications of OR and
- To expose the students with the knowledge of formulation of real life problems using the linear programming method.
- To make the students understand about the theory and practical application of transportation problems and assignment problems
- To introduce 'Game Theory-the science of strategy' to the students, which makes possible the analysis of the decision making process of interdependent subjects.
- To provide a framework to develop mathematical models for different types inventory systems.

Learning Outcomes:
After successful completion of this course, students should be able to:

- Understand the fundamental concepts of Operational Research Techniques
- Apply Linear Programming.
- Solve the Transportation and assignment problems
- Understand the Game Theory
- Use the Inventory Models

SYLLABUS OF DSE-1A
Theory
UNIT I **(15 hours)**
Introduction to OR and LPP
Definition and phases of O.R. Model building, various types of O.R. problems. Linear Programming Problem (L.P.P.): Mathematical formulation of the L.P.P, graphical solutions of L.P.P. Simplex method for solving L.P.P. Charne's M-technique for solving L.P.P. involving artificial variables. Special cases of L.P.P. Concept of Duality in L.P.P. Economic interpretation of Duality. Dual simplex method.

UNIT II **(15 hours)**

Transportation and Assignment Problem

Transportation Problem: Initial solution by North West corner rule, Least cost method and Vogel's approximation method (VAM), MODI's method to find the optimal solution, special cases of transportation problem. Assignment problem: Hungarian method to find optimal assignment, special cases of assignment problem.

UNIT III **(15 hours)**

Game Theory and Inventory Management

Game theory: Rectangular game, minimax - maximin principle, solution to rectangular game using graphical method, dominance and modified dominance property to reduce the game matrix and solution to rectangular game with mixed strategy. Network flow problems and shortest route problem. Inventory Management: ABC inventory system, characteristics of inventory system. EOQ Model and its variations, with and without shortages.

PRACTICAL/LAB WORK – (30 hours)

List of Practical:

1. Mathematical formulation of L.P.P and solving the problem using graphical method.
2. Simplex technique and Charne's Big M method involving artificial variables.
3. Identifying Special cases by Graphical and Simplex method and interpretation:
   a) Degenerate solution
   b) Unbounded solution
   c) Alternate solution
   d) Infeasible solution
4. Allocation problem using Transportation model.
5. Allocation problem using Assignment model.
6. Graphical solution to $mx2$ / $2xn$ rectangular game
7. Mixed strategy
8. To find optimal inventory policy for EOQ models and its variations.

Practical work to be conducted using electronic spreadsheet / EXCEL/ Statistical Software Package/ SPSS/ calculators/ TORA/WINQSB/LINGO

ESSENTIAL READINGS:

- Swarup, K., Gupta, P.K. and Man Mohan (2013). Operations Research, 16th Ed., Sultan Chand and Sons.
- Taha, H. A. (2007). Operations Research: An Introduction, 8thEd., Prentice Hall of India.

SUGGESTIVE READINGS:

- F.S. Hillier. G.J. Lieberman (2010). Introduction to Operations Research- Concepts and Cases, 9th Edition, Tata McGraw Hill.
- Donald Waters (2010): Inventory Control and Management, John Wiley.
- A. Ravindran, D. T. Phillips and James J. Solberg(2005). Operations Research- Principles and Practice, John Wiley & Sons,
- G. Hadley (2002). Linear Programming, Reprint.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE COURSE – 1B: PSYCHOLOGICAL AND EDUCATIONAL STATISTICS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Psychological and Educational Statistics	4	3	0	1	**Passed Class XII with Mathematics**	**Theory of Probability Distributions**

Learning Objectives:
The learning objectives include:
- To measure psychological traits and mental abilities
- To learn basic methods of test construction, item writing and item analysis
- To check the reliability and validity of test scores.

Learning Outcomes:
After successful completion of this course, students should be able to:
- Distinguish between Psychological measurement and physical measurement.
- Understand the meaning of Tests in Psychology and Education.
- Appreciate the uses and limitations of Psychological tests.
- Learn the meaning and purpose of Item writing and analysis.
- Understand concepts of reliability and validity of test scores and their differences.
- Convert raw scores into different transformed scores.
- Apply Scaling rankings and ratings in terms of the Normal Probability Curve.

SYLLABUS OF DSE-1B
Theory
Unit I **(15 hours)**
Basics of Educational Statistics
Introduction; need and importance of statistics in psychology and education. Measurements: Levels of measurements. Distinction between psychological and physical measurements; general problems, sources of errors. Tests: Meaning of tests in psychology and education; history of psychological measurement and testing, uses, limitations and varieties, characteristics of a good test, general steps of test construction. Test administration. Item writing - Meaning and types; Item analysis – meaning and purpose. Item difficulty (concepts only). Power tests and speed tests.

Unit II **(15 hours)**
Reliability and Validity
Reliability: Meaning, methods (or types); standard error of measurement, reliability of speed test, factors influencing reliability of test scores, factors for their improvement, estimation of true scores and index of reliability. Reliability of difference and composite scores. Validity:

Meaning; content, criterion related and construct validity. Statistical methods for calculating validity, factors influencing validity. Extra validity concerns, relation of validity to reliability.

Unit III **(15 hours)**
Psychological Statistics
Meaning of norm referencing and criterion referencing. Raw score transformations- percentile score, standard scores, normalized standard scores, T-scores, C-scores and Stanine scores. Intelligence: Definition. Types of intelligence test scores. Spearman's two-factor theory and Thomson group factors theory. Psychological scaling methods – Scaling of Individual test items in terms of difficulty, scaling of rankings & ratings in terms of the normal probability curve.

PRACTICAL/LAB WORK - 30 hours
List of Practical:

1. Computation of Reliability by Rulon and Kuder Richardson Formulas.
2. Finding reliability of a test whose length is increased/ decreased n times.
3. Finding index of reliability, standard error of measurement.
4. Finding validity/maximum validity when test length is increased n times/ indefinitely.
5. Finding relative difficulty of questions/ difference in difficulty between different tests.
6. Converting raw scores into Z-scores.
7. Converting raw scores into T-scores.
8. Calculation of T scores for a given frequency distribution.
9. Construction of C-scales and its diagrammatic representation.
10. Construction of Stanine-scales and its diagrammatic representation.
11. Calculation of percentile scores corresponding to rank of an individual among N individuals.
12. Finding numerical scores corresponding to grades or ratings by different judges.

Practical work to be conducted using electronic spreadsheet / EXCEL/ Statistical Software Package/ SPSS/ calculators.

ESSENTIAL READINGS:

- Garrett H. E. (2021). Statistics in psychology and education. Nation Press.
- Gregory R. J. (2016). Psychological testing: History Principles and Applications. (Updated seventh). Pearson.
- Singh, A. K. (2006). Tests, Measurements and Research in Behavioural Sciences. Bharati Bhavan.
- Anastasi A. & Urbina S. (1997). Psychological testing (7th ed.). Prentice Hall.

SUGGESTIVE READINGS:

- Gupta, S. C., & Kapoor, V. K. (2019). Fundamentals of applied statistics. Sultan Chand & Sons.
- Goon A M, Gupta M K and Dasgupta B (2018): Fundamentals of Statistics, Volume II, 9th Edition and 4th reprint.
- Mangal, S. K. (2016). Statistics in Psychology and Education. PHI Learning Pvt. Ltd..

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE FOR B. SC. (P)

DISCIPLINE SPECIFIC ELECTIVE COURSE – 1: TIME SERIES ANALYSIS AND INDEX NUMBERS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Time Series Analysis and Index Numbers	4	3	0	1	**Passed Class XII with Mathematics**	**Descriptive Statistics and Probability Theory**

Learning Objectives

The Learning Objectives of this course are as follows:

- Introduce the concept of time series, its components, and their estimation.
- Introduce the application of time series.
- Introduce the concept, formulation, and application of index numbers.

Learning outcomes

After completion of this course, the students will be able to:

- Understand the concepts of time series and index numbers.
- Formulate, solve, and analyse the use of time series and index numbers for real-world problems.

SYLLABUS OF DSE 1

Theory

Unit - 1 **(12 hours)**

Components of Time Series

Introduction to Time Series, Components of time series, Decomposition of time series- Additive and multiplicative model with their merits and demerits, Illustrations of time series, Measurement of trend by method of free-hand curve, method of semi-averages and method of least squares (linear, quadratic and exponential).

Unit - 2 **(15 hours)**

Trend and Seasonality

Fitting of modified exponential, Gompertz and logistic curve, Moving average method, Measurement of seasonal variations by method of simple averages, ratio to trend method, and ratio to moving average method.

Unit - III **(18 hours)**

Index Numbers

Introduction to Index numbers, Problems in the construction of index numbers, Construction of price and quantity index numbers: simple aggregate, weighted aggregate (Laspeyres, Paasche's, Drobish-Bowley, Marshall-Edgeworth's, Walsch and Fisher's Formula), simple and weighted average of price relatives, and chain base method, Criteria for a good index number, Errors in the measurement of price and quantity index numbers, Consumer price index number, its construction and uses, Uses and limitations of index numbers.

Practical - 30 Hours
List of Practicals:

1. Fitting of linear trend
2. Fitting of quadratic trend
3. Fitting of an exponential curve
4. Fitting of modified exponential curve by the method of
    a. Three selected points
    b. Partial sums
5. Fitting of Gompertz curve by the method of
    a. Three selected points
    b. Partial sums
6. Fitting of logistic curve by the method of three selected points
7. Fitting of trend by moving average method (for n even and odd)
8. Measurement of seasonal indices by
    a. Method of simple averages
    b. Ratio-to-trend method
    c. Ratio-to-moving-average method
9. Construction of price and quantity index numbers by simple aggregate method.
10. Construction of price and quantity index numbers by Laspeyres, Paasche's, Drobish-Bowley, Marshall-Edgeworth, Walsch and Fisher's Formula.
11. Construction of price and quantity index numbers by simple and weighted average of price relatives.
12. Construction of index number by Chain base method.
13. Construction of consumer price index number by
    a. Family budget method
    b. Aggregate expenditure method
14. Time Reversal Test and Factor Reversal Test

Practical work to be conducted using electronic spreadsheet / EXCEL/ Statistical Software Package/ SPSS/ calculators.

ESSENTIAL READINGS

● Goon A M, Gupta M K and Dasgupta B (2018): Fundamentals of Statistics, Volume II, 9th Edition and 4th reprint.
● Gupta, S.C. and Kapoor, V.K. (2014). Fundamentals of Applied Statistics, 11th Ed., Sultan Chand.
● Croxton, Fredrick E, Cowden, Dudley J. and Klein, S. (1973): Applied General Statistics, 3rd edition, Prentice Hall of India Pvt. Ltd.

SUGGESTIVE READING

● Mukhopadhyay, P. (1999). Applied Statistics, New Central Book Agency, Calcutta.
● Allen R.G.D. (1975): Index Numbers in Theory and Practice, Macmillan

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

COMMON POOL OF GENERIC ELECTIVES (GE) COURSES OFFERED BY DEPARTMENT OF STATISTICS
CATEGORY-VI

GENERIC ELECTIVES – : SAMPLING DISTRIBUTIONS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Sampling Distributions	4	3	0	1	**Passed Class XII with Mathematics**	Introductory Probability

Learning Objectives:

The learning objectives include:

- To understand the concept of sampling distributions and their applications in statistical inference.
- To understand the process of hypothesis testing.
- To have a clear understanding of when to apply various tests of hypothesis about population parameters using sample statistics and draw appropriate conclusions from the analysis.

Learning Outcomes:

After successful completion of this course, students should be able to:

- Understand the basic concepts of hypothesis testing, including framing of the null and alternative hypotheses.
- Apply hypothesis testing based on a single sample and two samples using both classical and p-value approaches.
- Understand the Chi-square distribution.
- Analyze categorical data by using Chi-square techniques.
- Apply t and F distributions

SYLLABUS OF GE-3A

Theory

Unit I **(15 hours)**

Large sample tests

Large sample tests: Definitions of random sample, parameter and statistic, sampling distribution of a statistic, sampling distribution of sample mean, standard errors of sample mean, and sample proportion. Null and alternative hypotheses, level of significance, Type I and Type II errors, their probabilities and critical region. Large sample tests, use of CLT for testing single proportion, difference of two proportions, single mean, difference of two means, standard deviation and difference of standard deviations by classical and p-value approaches.

Unit II **(15 hours)**

Chi square distribution

Chi square distribution: Definition and derivation of $\chi 2$ distribution with n degrees of freedom (d.f.) using m.g.f., nature of probability curve for different degrees of freedom, mean, variance, m.g.f., cumulant generating function, mode, additive property and limiting form of $\chi 2$ distribution. Tests of significance and confidence intervals based on $\chi 2$ distribution.

Unit III **(15 hours)**

Exact Sampling Distributions

t and F distributions: Student's t and Fishers t-distributions, Derivation of its p.d.f., nature of probability curve with different degrees of freedom, mean, variance, moments and limiting form of t distribution. Snedecore's F-distribution: Derivation of F distribution, nature of probability curve with different degrees of freedom, mean, variance and mode. Distribution of $1/F(n_1,n_2)$. Relationship between t, F and $\chi 2$ distributions. Test of significance and confidence intervals based on t and F distributions.

PRACTICAL/LAB WORK - 30 hours

List of Practicals

1. Large Sample Tests:

(i) Testing of significance and confidence intervals for single proportion and difference of two proportions.

(ii) Testing of significance and confidence intervals for single mean and difference of two means.

(iii) Testing of significance and confidence intervals for difference of two standard deviations.

2. Tests based on Chi-Square Distribution:

(i) To test if the population variance has a specific value and its confidence intervals.

(ii) To test the goodness of fit.

(iii) To test the independence of attributes.

(iv) Test based on 2 x 2 contingency table without and with Yates' corrections.

3. Tests based on t- Distribution and F- Distribution:

(i) Testing of significance and confidence intervals for single mean and difference of two means and paired t – test.

(ii) Testing of significance and confidence intervals of an observed sample correlation coefficient.

(iii) Testing and confidence intervals of equality of two population variances.

Practical work to be conducted using electronic spreadsheet / EXCEL/ Statistical Software Package/ SPSS/ calculators.

ESSENTIAL READINGS :

● Gupta, S. C. and Kapoor, V. K. (2020). Fundamentals of Mathematical Statistics, 12th Ed., S. Chand and Sons. Delhi.

● Goon, A.M., Gupta, M.K. and Dasgupta, B. (2003). An Outline of Statistical Theory, Vol. I, 4th Ed., World Press, Kolkata.

● Rohatgi, V. K. and Saleh, A.K. Md. E. (2009). An Introduction to Probability and Statistics, 2nd Ed., (Reprint) John Wiley and Sons.

SUGGESTIVE READINGS:

● Hogg, R.V. and Tanis, E.A. (2009). A Brief Course in Mathematical Statistics. Pearson Education.
● Mood, M.A., Graybill, F.A. and Boes, C.D. (2007). Introduction to the Theory of Statistics, 3rd Ed., (Reprint).Tata McGraw-Hill Pub. Co. Ltd.
● Johnson, R.A. and Bhattacharya, G.K. (2001). Statistics-Principles and Methods, 4th Ed., John Wiley and Sons.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

Major 1/ Minor 1: Descriptive Statistics and Probability Theory
Major 3/ Minor 2: Statistical Methods
GE -2A: Introductory Probability

DEPARTMENT OF MATHEMATICS

B.Sc. (Hons) MATHEMATICS

Category-I

DISCIPLINE SPECIFIC CORE COURSE -7: GROUP THEORY

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Group Theory	4	3	1	0	Class XII pass with Mathematics	Algebra

Learning Objectives

The primary objective of this course is to introduce:

- Symmetric groups, normal subgroups, factor groups, and direct products of groups.
- The notions of group homomorphism to study the isomorphism theorems with applications.
- Classification of groups with small order according to isomorphisms.

Learning Outcomes

This course will enable the students to:

- Analyse the structure of 'small' finite groups, and examine examples arising as groups of permutations of a set, symmetries of regular polygons.
- Understand the significance of the notion of cosets, Lagrange's theorem and its consequences.
- Know about group homomorphisms and isomorphisms and to relate groups using these mappings.
- Express a finite abelian group as the direct product of cyclic groups of prime power orders.
- Learn about external direct products and its applications to data security and electric circuits.

SYLLABUS OF DSC - 7

Unit – 1 **(18 hours)**

Permutation Groups, Lagrange's Theorem and Normal Subgroups

Permutation groups and group of symmetries, Cycle notation for permutations and properties, Even and odd permutations, Alternating groups; Cosets and its properties, Lagrange's theorem and consequences including Fermat's Little theorem, Number of elements in product of two finite subgroups; Normal subgroups, Factor groups, Cauchy's theorem for finite Abelian groups.

Unit – 2 **(15 hours)**

Group Homomorphisms and Automorphisms

Group homomorphisms, isomorphisms and properties, Cayley's theorem; First, Second and Third isomorphism theorems for groups; Automorphism, Inner automorphism, Automorphism groups, Automorphism groups of cyclic groups, Applications of factor groups to automorphism groups.

Unit – 3 **(12 hours)**
Direct Products of Groups and Fundamental Theorem of Finite Abelian Groups
External direct products of groups and its properties, The group of units modulo n as an external direct product, Applications to data security and electric circuits; Internal direct products; Fundamental theorem of finite abelian groups and its isomorphism classes.

Essential Reading

1. Gallian, Joseph. A. (2017). Contemporary Abstract Algebra (9th ed.). Cengage Learning India Private Limited, Delhi. Indian Reprint 2021.

Suggestive Readings

- Artin, Michael. (1991). Algebra (2nd ed.). Pearson Education. Indian Reprint 2015.
- Dummit, David S., & Foote, Richard M. (2016). Abstract Algebra (3rd ed.). Student Edition. Wiley India.
- Herstein, I. N. (1975). Topics in Algebra (2nd ed.). Wiley India, Reprint 2022.
- Rotman, Joseph J. (1995). An Introduction to The Theory of Groups (4th ed.). Springer-Verlag, New York.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE -8: RIEMANN INTEGRATION

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Riemann Integration	4	3	1	0	Class XII pass with Mathematics	Elementary Real Analysis, and Calculus

Learning Objectives

The primary objective of this course is to:

- Understand the integration of bounded functions on a closed and bounded interval and its extension to the cases where either the interval of integration is infinite, or the integrand has infinite limits at a finite number of points on the interval of integration.
- Learn some of the properties of Riemann integrable functions, its generalization and the applications of the fundamental theorems of integration.
- Get an exposure to the utility of integration for practical purposes.

Learning Outcomes

This course will enable the students to:

- Learn about some of the classes and properties of Riemann integrable functions, and the applications of the Riemann sums to the volume and surface of a solid of revolution.
- Get insight of integration by substitution and integration by parts.
- Know about convergence of improper integrals including, beta and gamma functions.

SYLLABUS OF DSC - 8

Unit – 1 **(18 hours)**
The Riemann Integral
Definition of upper and lower Darboux sums, Darboux integral, Inequalities for upper and lower Darboux sums, Necessary and sufficient conditions for the Darboux integrability; Riemann's definition of integrability by Riemann sum and the equivalence of Riemann's and Darboux's definitions of integrability; Definition and examples of the Riemann-Stieltjes integral.

Unit – 2 **(15 hours)**
Properties of The Riemann Integral and Fundamental Theorems
Riemann integrability of monotone functions and continuous functions, Properties of Riemann integrable functions; Definitions of piecewise continuous and piecewise monotone functions and their Riemann integrability; Intermediate value theorem for integrals, Fundamental Theorems of Calculus (I and II).

Unit – 3 **(12 hours)**
Applications of Integrals and Improper Integrals
Methods of integration: integration by substitution and integration by parts; Volume by slicing and cylindrical shells, Length of a curve in the plane and the area of surfaces of revolution.
Improper integrals of Type-I, Type-II and mixed type, Convergence of improper integrals,
The beta and gamma functions and their properties.

Essential Readings

1. Ross, Kenneth A. (2013). Elementary Analysis: The Theory of Calculus (2nd ed.). Undergraduate Texts in Mathematics, Springer.
2. Anton, Howard, Bivens Irl and Davis Stephens (2012). Calculus (10th edn.). John Wiley & Sons, Inc.
3. Denlinger, Charles G. (2011). Elements of Real Analysis, Jones & Bartlett India Pvt. Ltd., Indian Reprint.
4. Ghorpade, Sudhir R. and Limaye, B. V. (2006). A Course in Calculus and Real Analysis. Undergraduate Texts in Mathematics, Springer (SIE). Indian Reprint.

Suggestive Readings

- Bartle, Robert G., & Sherbert, Donald R. (2015). Introduction to Real Analysis (4th ed.). Wiley, Indian Edition.
- Kumar Ajit and Kumaresan S. (2014). A Basic Course in Real Analysis. CRC Press, Taylor & Francis Group, Special Indian Edition.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE– 9: DISCRETE MATHEMATICS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Discrete Mathematics	4	3	0	1	Class XII pass with Mathematics	Algebra and Linear Algebra

Learning Objectives

The primary objective of the course is to:

- Make students embark upon a journey of enlightenment, starting from the abstract concepts in mathematics to practical applications of those concepts in real life.
- Make the students familiar with the notion of partially ordered set and a level up with the study of lattice, Boolean algebra and related concepts.
- Culminate the journey of learning with practical applications using the knowledge attained from the abstract concepts learnt in the course.

Learning Outcomes

This course will enable the students to:

- Understand the notion of partially ordered set, lattice, Boolean algebra with applications.
- Handle the practical aspect of minimization of switching circuits to a great extent with the methods discussed in this course.
- Apply the knowledge of Boolean algebras to logic, set theory and probability theory.

SYLLABUS OF DSC - 9

Unit – 1 **(15 hours)**

Cardinality and Partially Ordered Sets

The cardinality of a set; Definitions, examples and basic properties of partially ordered sets, Order-isomorphisms, Covering relations, Hasse diagrams, Dual of an ordered set, Duality principle, Bottom and top elements, Maximal and minimal elements, Zorn's lemma, Building new ordered sets, Maps between ordered sets.

Unit – 2 **(15 hours)**

Lattices

Lattices as ordered sets, Lattices as algebraic structures, Sublattices, Products, Lattice isomorphism; Definitions, examples and properties of modular and distributive lattices; The $M_3 – N_5$ theorem with applications, Complemented lattice, Relatively complemented lattice, Sectionally complemented lattice.

Unit – 3 **(15 hours)**

Boolean Algebras and Applications

Boolean algebras, De Morgan's laws, Boolean homomorphism, Representation theorem, Boolean polynomials, Boolean polynomial functions, Equivalence of Boolean polynomials, Disjunctive normal form and conjunctive normal form of Boolean polynomials; Minimal forms of Boolean polynomials, Quine-McCluskey method, Karnaugh diagrams, Switching circuits and applications, Applications of Boolean algebras to logic, set theory and probability theory.

Practical (30 hours):

Practical/Lab work to be performed in a computer Lab using any of the Computer Algebra System Software such as Mathematica/MATLAB /Maple/Maxima/Scilab/SageMath etc., for the following problems based on:

1) Expressing relations as ordered pairs and creating relations.
2) Finding whether or not, a given relation is:
   i. Reflexive ii. Antisymmetric iii. Transitive iv. Partial order
3) Finding the following for a given partially ordered set
   i. Covering relations.
   ii. The corresponding Hasse diagram representation.
   iii. Minimal and maximal elements.
4) Finding the following for a subset *S* of a given partially ordered set *P*
   i. Whether a given element in *P* is an upper bound (lower bound) of *S* or not.
   ii. Set of all upper bounds (lower bounds) of *S*.
   iii. The least upper bound (greatest lower bound) of *S*, if it exists.
5) Creating lattices and determining whether or not, a given partially ordered set is a lattice.
6) Finding the following for a given Boolean polynomial function:
   i. Representation of Boolean polynomial function and finding its value when the Boolean variables in it take particular values over the Boolean algebra $\{0,1\}$.
   ii. Display in table form of all possible values of Boolean polynomial function over the Boolean algebra $\{0,1\}$.
7) Finding the following:
   i. Dual of a given Boolean polynomial/expression.
   ii. Whether or not two given Boolean polynomials are equivalent.
   iii. Disjunctive normal form (Conjunctive normal form) from a given Boolean expression.
   iv. Disjunctive normal form (Conjunctive normal form) when the given Boolean polynomial function is expressed by a table of values.
8) Representing a given circuit diagram (expressed using gates) in the form of Boolean expression.
9) Minimizing a given Boolean expression to find minimal expressions.

Essential Readings

1. Davey, B. A., & Priestley, H. A. (2002). Introduction to Lattices and Order (2nd ed.). Cambridge University press, Cambridge.
2. Goodaire, Edgar G., & Parmenter, Michael M. (2006). Discrete Mathematics with Graph Theory (3rd ed.). Pearson Education Pvt. Ltd. Indian Reprint.
3. Lidl, Rudolf & Pilz, Gunter. (2004). Applied Abstract Algebra (2nd ed.), Undergraduate Texts in Mathematics. Springer (SIE). Indian Reprint.

Suggested Readings

- Donnellan, Thomas. (1999). Lattice Theory (1st ed.). Khosla Pub. House. Indian Reprint.
- Rosen, Kenneth H. (2019). Discrete Mathematics and its Applications (8th ed.), Indian adaptation by Kamala Krithivasan. McGraw-Hill Education. Indian Reprint 2021.

B.Sc. (Hons) Mathematics, Semester-III, DSE-Courses

DISCIPLINE SPECIFIC ELECTIVE COURSE -1(i): GRAPH THEORY

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Graph Theory	4	3	1	0	Class XII pass with Mathematics	Nil

Learning Objectives
The primary objective of this course is to introduce:
- Problem-solving techniques using various concepts of graph theory.
- Various properties like planarity and chromaticity of graphs.
- Several applications of these concepts in solving practical problems.

Learning Outcomes
This course will enable the students to:
- Learn modelling of real-world problems by graphs.
- Know characteristics of different classes of graphs.
- Learn representation of graphs in terms of matrices.
- Learn algorithms to optimize a solution.
- Understand some properties of graphs and their applications in different practical situations.

SYLLABUS OF DSE - 1(i)

Unit – 1 **(12 hours)**
Graphs, Paths and Circuits
Definition, Examples and basic properties of graphs, Subgraphs, Pseudographs, Complete graphs, Bipartite graphs, Isomorphism of graphs, Paths and circuits, Connected graphs, Eulerian circuits, Hamiltonian cycles, Adjacency matrix, Weighted graph, Travelling salesman problem, Shortest path, Dijkstra's algorithm.

Unit – 2 **(15 hours)**
Applications of Paths and Circuits, Trees
Applications of Path and Circuits: The Chinese Postman Problem, Digraphs, Bellman-Ford Algorithm, Tournaments, Scheduling Problem, Trees, Properties of Trees, Spanning Trees, Minimum Spanning Tree Algorithms.

Unit – 3 **(18 hours)**
Connectivity and Graph Coloring, Planar Graphs
Cut-vertices, Blocks and their Characterization, Connectivity and edge-connectivity, Planar graphs, Euler's formula, Kuratowski theorem, Graph coloring and applications, Matchings, Hall's theorem, Independent sets and covers.

Essential Readings

1. Goodaire, Edgar G., & Parmenter, Michael M. (2006). Discrete Mathematics with Graph Theory (3rd ed.). Pearson Education Pvt. Ltd. Indian Reprint.
2. Chartrand, Gary, & Zhang, Ping (2012). A First Course in Graph Theory. Dover Publications.

Suggestive Readings

- Bondy, J. A., and Murty, U.S.R. (2008). Graph Theory. Graduate Texts in Mathematics, Springer.
- Diestel, Reinhard (2017). Graph Theory (5th ed.). Graduate Texts in Mathematics, Springer.
- West, Douglas B. (2001). Introduction to Graph Theory (2nd ed.). Prentice Hall. Indian Reprint.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE COURSE– 1(ii): MATHEMATICAL PYTHON

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Mathematical Python	4	3	0	1	Class XII pass with Mathematics	Basic knowledge of Python

Learning Objectives

The Learning Objectives of this course are as follows:

- To be able to model and solve mathematical problems using Python Programs.
- To experience utility of open-source resources for numerical and symbolic mathematical software systems.

Learning Outcomes

This course will enable the students to use Python:

- For numerical and symbolic computation in mathematical problems from calculus, algebra, and geometry.
- To tabulate and plot diverse graphs of functions and understand tracing of shapes, geometries, and fractals.
- To prepare smart documents with LaTeX interface.

SYLLABUS OF DSE - 1(ii)

Theory

Unit – 1 **(15 hours)**

Drawing Shapes, Graphing and Visualization

Drawing diverse shapes using code and Turtle; Using matplotlib and NumPy for data organization, Structuring and plotting lines, bars, markers, contours and fields, managing subplots and axes; Pyplot and subplots, Animations of decay, Bayes update, Random walk.

Unit – 2 **(18 hours)**

Numerical and Symbolic Solutions of Mathematical Problems

NumPy for scalars and linear algebra on n-dimensional arrays; Computing eigenspace, Solving dynamical systems on coupled ordinary differential equations, Functional programming fundamentals using NumPy; Symbolic computation and SymPy: Differentiation and integration of functions, Limits, Solution of ordinary differential equations, Computation of eigenvalues, Solution of expressions at multiple points (lambdify), Simplification of expressions, Factorization, Collecting and canceling terms, Partial fraction decomposition, Trigonometric simplification, Exponential and logarithms, Series expansion and finite differences, Solvers, Recursive equations.

Unit – 3 **(12 hours)**

Document Generation with Python and LaTeX

Pretty printing using SymPy; Pandas API for IO tools: interfacing Python with text/csv, HTML, LaTeX, XML, MSExcel, OpenDocument, and other such formats; Pylatex and writing document files from Python with auto-computed values, Plots and visualizations.

Practical (30 hours): Software labs using IDE such as Spyder and Python Libraries.

- Installation, update, and maintenance of code, troubleshooting.
- Implementation of all methods learned in theory.
- Explore and explain API level integration and working of two problems with standard Python code.

Essential Readings

1. Farrell, Peter (2019). Math Adventures with Python. No Starch Press. ISBN Number: 978-1-59327-867-0.
2. Farrell, Peter and et al. (2020). The Statistics and Calculus with Python Workshop. Packet Publishing Ltd. ISBN: 978-1-80020-976-3.
3. Saha, Amit (2015). Doing Math with Python. No Starch Press. ISBN: 978-1-59327-640-9

Suggested Readings

- Morley, Sam (2022). Applying Math with Python (2nd ed.). Packet Publishing Ltd. ISBN: 978-1-80461-837-0
- Online resources and documentation on the libraries, such as:
    - https://matplotlib.org
    - https://sympy.org
    - https://pandas.pydata.org
    - https://numpy.org
    - https://pypi.org
    - https://patrickwalls.github.io/mathematicalpython/

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE COURSE-1(iii): NUMBER THEORY

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Number Theory	4	3	1	0	Class XII pass with Mathematics	Algebra

Learning Objectives

The primary objective of this course is to introduce:

- The number theoretic techniques of computations with the flavour of abstraction.
- The Euclidean algorithm, linear Diophantine equations, congruence equations, arithmetic functions and their applications, Fermat's little, Euler's and Wilson's theorems.
- Primitive roots, quadratic residues and nonresidues, the Legendre symbol and the law of Quadratic Reciprocity.
- Introduction to cryptography, public-key cryptosystems and applications.

Learning Outcomes

This course will enable the students to:

- Use modular arithmetic in solving linear and system of linear congruence equations.
- Work with the number theoretic functions, their properties and their use.
- Learn the forms of positive integers that possess primitive roots and the Quadratic Reciprocity Law which deals with the solvability of quadratic congruences.
- Understand the public-key cryptosystems, in particular, RSA.

SYLLABUS OF DSE - 1(iii)

Unit – 1 **(12 hours)**

Linear Diophantine equation and Theory of Congruences

The Euclidean Algorithm and linear Diophantine equation; Least non-negative residues and complete set of residues modulo n; Linear congruences, The Chinese remainder theorem and system of linear congruences in two variables; Fermat's little theorem, Wilson's theorem and its converse, Application to solve quadratic congruence equation modulo odd prime p.

Unit – 2 **(21 hours)**

Number-Theoretic Functions and Primitive Roots

Number-theoretic functions for the sum and number of divisors, Multiplicative function, Möbius inversion formula and its properties; Greatest integer function with an application to the calendar; Euler's Phi-function, Euler's theorem and some properties of the Phi-function; The order of an integer modulo n and primitive roots for primes, Primitive roots of composite numbers n: when n is of the form 2^k, and when n is a product of two coprime numbers.

Unit – 3 **(12 hours)**

Quadratic Reciprocity Law and Public Key Cryptosystems

The quadratic residue and nonresidue of an odd prime and Euler's criterion, The Legendre symbol and its properties, Quadratic Reciprocity law and its application; Introduction to cryptography, Hill's cipher, Public-key cryptography and RSA.

Essential Reading

1. Burton, David M. (2011). Elementary Number Theory (7th ed.). McGraw-Hill Education Pvt. Ltd. Indian Reprint 2017.

Suggestive Readings

- Andrews, George E. (1994). Number Theory. Dover publications, Inc. New York.
- Robbins, Neville (2007). Beginning Number Theory (2nd ed.). Narosa Publishing House Pvt. Ltd. Delhi.
- Rosen, Kenneth H. (2011). Elementary Number Theory and its Applications (6th ed.). Pearson Education. Indian Reprint 2015.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

B.A. (Prog.) with Mathematics as Major

Category-II

DISCIPLINE SPECIFIC CORE COURSE – 3: THEORY OF EQUATIONS AND SYMMETRIES

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Theory of Equations and Symmetries	4	3	1	0	Class X pass with Mathematics	Nil

Learning Objectives
The goal of this paper is to acquaint students with certain ideas about:
- Integral roots, rational roots, an upper bound on number of positive or negative roots of a polynomial.
- Finding roots of cubic and quartic equations in special cases using elementary symmetric functions.
- Using Cardon's and Descartes' methods, respectively.

Learning Outcomes
After completion of this paper, the students will be able to:
- Understand the nature of the roots of polynomial equations and their symmetries.
- Solve cubic and quartic polynomial equations with special condition on roots and in general.
- Find symmetric functions in terms of the elementary symmetric polynomials.

SYLLABUS OF DSC-3

Unit – 1 **(18 hours)**
Polynomial Equations and Properties
General properties of polynomials and equations; Fundamental theorem of algebra and its consequences; Theorems on imaginary, integral and rational roots; Descartes' rule of signs for positive and negative roots; Relations between the roots and coefficients of equations, Applications to solution of equations when an additional relation among the roots is given; De Moivre's theorem for rational indices, the nth roots of unity and symmetries of the solutions.

Unit – 2 **(12 hours)**
Cubic and Biquadratic (Quartic) Equations

Transformation of equations (multiplication, reciprocal, increase/diminish in the roots by a given quantity), Removal of terms; Cardon's method of solving cubic and Descartes' method of solving biquadratic equations.

Unit – 3 **(15 hours)**

Symmetric Functions

Elementary symmetric functions and symmetric functions of the roots of an equation; Newton's theorem on sums of the like powers of the roots; Computation of symmetric functions such as $\sum\alpha^2\beta,\ \sum\alpha^2\beta^2,\ \sum\alpha^2\beta\gamma,\ \sum\frac{1}{\alpha^2\beta\gamma},\ \sum\alpha^{-3},\ \sum(\beta+\gamma-\alpha)^2,\ \sum\frac{\alpha^2+\beta\gamma}{\beta+\gamma},\ldots$ of polynomial equations; Transformation of equations by symmetric functions and in general.

Essential Readings

1. Burnside, W.S., & Panton, A.W. (1979). The Theory of Equations (11th ed.). Vol. 1. Dover Publications, Inc. (4th Indian reprint. S. Chand & Co. New Delhi).
2. Dickson, Leonard Eugene (2009). First Course in the Theory of Equations. John Wiley & Sons, Inc. The Project Gutenberg eBook: http://www.gutenberg.org/ebooks/29785

Suggestive Readings

- Prasad, Chandrika (2017). Text Book of Algebra and Theory of Equations. Pothishala Pvt Ltd.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC CORE COURSE – A-3: DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Differential Equations	4	3	1	0	Class XII pass with Mathematics	Nil

Learning Objectives

The primary objective of this course is to introduce:

- Ordinary and partial differential equations.
- Basic theory of higher order linear differential equations, Wronskian and its properties.
- Various techniques to find the solutions of above differential equations which provide a basis to model complex real-world situations.

Learning Outcomes

This course will enable the students to:

- Solve the exact, linear, Bernoulli equations, find orthogonal trajectories and solve rate problems.

- Apply the method of undetermined coefficients and variation of parameters to solve linear differential equations.
- Solve Cauchy-Euler equations and system of linear differential equations.
- Formulate and solve various types of first and second order partial differential equations.

SYLLABUS OF DISCIPLINE A-3

Unit – 1 **(15 hours)**
Ordinary Differential Equations
First order ordinary differential equations: Basic concepts and ideas, First order Exact differential equations, Integrating factors and rules to find integrating factors, Linear equations and Bernoulli equations, Initial value problems, Applications of first order differential equations: Orthogonal trajectories and Rate problems; Basic theory of higher order linear differential equations, Wronskian and its properties.

Unit – 2 **(12 hours)**
Explicit Methods of Solving Higher-Order Linear Differential Equations
Linear homogeneous equations with constant coefficients, Linear non-homogeneous equations, Method of undetermined coefficients, Method of variation of parameters, Two-point boundary value problems, Cauchy-Euler equations, System of linear differential equations.

Unit – 3 **(18 hours)**
First and Second Order Partial Differential Equations
Classification and Construction of first-order partial differential equations, Method of characteristics and general solutions of first-order partial differential equations, Canonical forms and method of separation of variables for first order partial differential equations; Classification and reduction to canonical forms of second-order linear partial differential equations and their general solutions.

Essential Readings
1. Myint-U, Tyn and Debnath, Lokenath (2007). Linear Partial Differential Equations for Scientist and Engineers (4th ed.). Birkhäuser. Indian Reprint.
2. Ross, Shepley L. (1984). Differential Equations (3rd ed.). John Wiley & Sons.

Suggestive Readings
- Edwards, C. Henry, Penney, David E., & Calvis, David T. (2015). Differential Equations and Boundary Value Problems: Computing and Modeling (5th ed.). Pearson Education.
- Kreyszig, Erwin. (2011). Advanced Engineering Mathematics (10th ed.). Wiley India.
- Sneddon I. N. (2006). Elements of Partial Differential Equations. Dover Publications.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

B.A./B.Sc. (Prog.) with Mathematics as Non-Major

Category-III

DISCIPLINE SPECIFIC CORE COURSE – A-3:
DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Differential Equations	4	3	1	0	Class XII pass with Mathematics	Nil

Learning Objectives
The primary objective of this course is to introduce:
- Ordinary and partial differential equations.
- Basic theory of higher order linear differential equations, Wronskian and its properties.
- Various techniques to find the solutions of above differential equations which provide a basis to model complex real-world situations.

Learning Outcomes
This course will enable the students to:
- Solve the exact, linear, Bernoulli equations, find orthogonal trajectories and solve rate problems.
- Apply the method of undetermined coefficients and variation of parameters to solve linear differential equations.
- Solve Cauchy-Euler equations and System of linear differential equations.
- Formulate and solve various types of first and second order partial differential equations.

SYLLABUS of Discipline A-3

Unit – 1 **(15 hours)**
Ordinary Differential Equations
First order ordinary differential equations: Basic concepts and ideas, First order Exact differential equations, Integrating factors and rules to find integrating factors, Linear equations and Bernoulli equations, Initial value problems, Applications of first order differential equations: Orthogonal trajectories and Rate problems; Basic theory of higher order linear differential equations, Wronskian and its properties.

Unit – 2 **(12 hours)**
Explicit Methods of Solving Higher-Order Linear Differential Equations

Linear homogeneous equations with constant coefficients, Linear non-homogeneous equations, Method of undetermined coefficients, Method of variation of parameters, Two-point boundary value problems, Cauchy-Euler equations, System of linear differential equations.

Unit – 3 (18 hours)

First and Second Order Partial Differential Equations

Classification and Construction of first-order partial differential equations, Method of characteristics and general solutions of first-order partial differential equations, Canonical forms and method of separation of variables for first order partial differential equations; Classification and reduction to canonical forms of second-order linear partial differential equations and their general solutions.

Essential Readings

1. Myint-U, Tyn and Debnath, Lokenath (2007). Linear Partial Differential Equations for Scientist and Engineers (4th ed.). Birkhäuser. Indian Reprint.
2. Ross, Shepley L. (1984). Differential Equations (3rd ed.). John Wiley & Sons.

Suggestive Readings

- Edwards, C. Henry, Penney, David E., & Calvis, David T. (2015). Differential Equations and Boundary Value Problems: Computing and Modeling (5th ed.). Pearson Education.
- Kreyszig, Erwin. (2011). Advanced Engineering Mathematics (10th ed.). Wiley India.
- Sneddon I. N. (2006). Elements of Partial Differential Equations. Dover Publications.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

B.Sc. (Physical Sciences/Mathematical Sciences) with Mathematics as one of the Core Discipline

Category-III

DISCIPLINE SPECIFIC CORE COURSE – A-3: DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Differential Equations	4	3	1	0	Class XII pass with Mathematics	Nil

Learning Objectives
The primary objective of this course is to introduce:
- Ordinary and partial differential equations.
- Basic theory of higher order linear differential equations, Wronskian and its properties.
- Various techniques to find the solutions of above differential equations which provide a basis to model complex real-world situations.

Learning Outcomes
This course will enable the students to:
- Solve the exact, linear, Bernoulli equations, find orthogonal trajectories and solve rate problems.
- Apply the method of undetermined coefficients and variation of parameters to solve linear differential equations.
- Solve Cauchy-Euler equations and System of linear differential equations.
- Formulate and solve various types of first and second order partial differential equations.

SYLLABUS of Discipline A-3

Unit – 1 **(15 hours)**
Ordinary Differential Equations
First order ordinary differential equations: Basic concepts and ideas, First order Exact differential equations, Integrating factors and rules to find integrating factors, Linear equations and Bernoulli equations, Initial value problems, Applications of first order differential equations: Orthogonal trajectories and Rate problems; Basic theory of higher order linear differential equations, Wronskian and its properties.

Unit – 2 **(12 hours)**
Explicit Methods of Solving Higher-Order Linear Differential Equations

Linear homogeneous equations with constant coefficients, Linear non-homogeneous equations, Method of undetermined coefficients, Method of variation of parameters, Two-point boundary value problems, Cauchy-Euler equations, System of linear differential equations.

Unit – 3 **(18 hours)**

First and Second Order Partial Differential Equations

Classification and Construction of first-order partial differential equations, Method of characteristics and general solutions of first-order partial differential equations, Canonical forms and method of separation of variables for first order partial differential equations; Classification and reduction to canonical forms of second-order linear partial differential equations and their general solutions.

Essential Readings

1. Myint-U, Tyn and Debnath, Lokenath (2007). Linear Partial Differential Equations for Scientist and Engineers (4th ed.). Birkhäuser. Indian Reprint.
2. Ross, Shepley L. (1984). Differential Equations (3rd ed.). John Wiley & Sons.

Suggestive Readings

- Edwards, C. Henry, Penney, David E., & Calvis, David T. (2015). Differential Equations and Boundary Value Problems: Computing and Modeling (5th ed.). Pearson Education.
- Kreyszig, Erwin. (2011). Advanced Engineering Mathematics (10th ed.). Wiley India.
- Sneddon I. N. (2006). Elements of Partial Differential Equations. Dover Publications.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DSE Courses of B.Sc. (Physical Sciences/Mathematical Sciences) Sem-III

DISCIPLINE SPECIFIC ELECTIVE -1(i): COMBINATORICS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Combinatorics	4	3	1	0	Class XII pass with Mathematics	Nil

Learning Objectives

The primary objective of this course is to:

- Introduce various techniques of permutations, combinations and inclusion-exclusion.
- Learn basic models of generating functions and recurrence relations in their application to the theory of integer partitions.

Learning Outcomes

After completing the course, student will:

- Enhance the mathematical logical skills by learning different enumeration techniques.
- Be able to apply these techniques in solving problems in other areas of mathematics.
- Be trained to provide reasoning and arguments to justify conclusions.

SYLLABUS OF DSE-1(i)

Unit - 1 **(15 hours)**

Basics of Combinatorics

Basic counting principles, Permutations and Combinations (with and without repetitions), Binomial coefficients, Multinomial coefficients, Counting subsets of size *k*; Set-partitions, The inclusion-exclusion principle and applications.

Unit - 2 **(18 hours)**

Generating Functions and Recurrence Relations

Generating functions: Generating function models, Calculating coefficients of generating functions, Polynomial expansions, Binomial identity, Exponential generating functions.
Recurrence relations: Recurrence relation models, Divide-and-conquer relations, Solution of linear recurrence relations, Solutions by generating functions.

Unit – 3 **(12 hours)**

Partition

Partition theory of integers: Ordered partition, Unordered partition, Ferrers diagram, Conjugate of partition, Self-conjugate partition, Durfee square, Euler's pentagonal theorem.

Essential Readings

1. Sane, Sharad S. (2013). Combinatorial Techniques. Hindustan Book Agency (India).
2. Tucker, Alan (2012). Applied Combinatorics (6th ed.). John Wiley & Sons, Inc.

Suggested Readings

- Brualdi, Richard A. (2009). Introductory Combinatorics (5th ed.). Pearson Education Inc.
- Cameron, Peter J. (1994). Combinatorics: Topics, Techniques, Algorithms. Cambridge University Press.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE COURSE-1(ii): ELEMENTS OF NUMBER THEORY

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Elements of Number Theory	4	3	1	0	Class XII pass with Mathematics	Nil

Learning Objectives

The primary objective of this course is to introduce:

- The Euclidean algorithm and linear Diophantine equations, the Fundamental theorem of arithmetic and some of the open problems of number theory viz. the Goldbach conjecture.
- The modular arithmetic, linear congruence equations, system of linear congruence equations, arithmetic functions and multiplicative functions, e.g., Euler's Phi-function.
- Introduction of the simple encryption and decryption techniques, and the numbers of specific forms viz. Mersenne numbers, Fermat numbers etc.

Learning Outcomes

This course will enable the students to:

- Get familiar with the basic number-theoretic techniques.
- Comprehend some of the open problems in number theory.
- Learn the properties and use of number-theoretic functions and special types of numbers.
- Acquire knowledge about public-key cryptosystems, particularly RSA.

SYLLABUS OF DSE-1(ii)

Unit – 1 **(12 hours)**

Divisibility and Prime Numbers

Revisiting: The division algorithm, divisibility and the greatest common divisor. Euclid's lemma; The Euclidean algorithm, Linear Diophantine equations; The Fundamental theorem of Arithmetic, The sieve of Eratosthenes, Euclid theorem and the Goldbach conjecture; The Fibonacci sequence and its nature.

Unit – 2 **(21 hours)**

Theory of Congruences and Number-Theoretic Functions

Congruence relation and its basic properties, Linear congruences and the Chinese remainder theorem, System of linear congruences in two variables; Fermat's little theorem and its generalization, Wilson's theorem and its converse; Number-theoretic functions for sum and the number of divisors of a positive integer, Multiplicative functions, The greatest integer function; Euler's Phi-function and its properties.

Unit – 3 **(12 hours)**

Public Key Encryption and Numbers of Special Form

Basics of cryptography, Hill's cipher, Public-key cryptosystems and RSA encryption and decryption technique; Introduction to perfect numbers, Mersenne numbers and Fermat numbers.

Essential Reading

1. Burton, David M. (2011). Elementary Number Theory (7th ed.). McGraw-Hill Education Pvt. Ltd. Indian Reprint 2017.

Suggestive Readings

- Jones, G. A., & Jones, J. Mary. (2005). Elementary Number Theory. Springer Undergraduate Mathematics Series (SUMS). Indian Reprint.
- Robbins, Neville (2007). Beginning Number Theory (2nd ed.). Narosa Publishing House Pvt. Ltd. Delhi.
- Rosen, Kenneth H. (2011). Elementary Number Theory and its Applications (6th ed.). Pearson Education. Indian Reprint 2015.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

DISCIPLINE SPECIFIC ELECTIVE COURSE - DSE-1(iii): THEORY OF EQUATIONS AND SYMMETRIES

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Theory of Equations and Symmetries	4	3	1	0	Class X pass with Mathematics	Nil

Learning Objectives

The goal of this paper is to acquaint students with certain ideas about:

- Integral roots, rational roots, an upper bound on number of positive or negative roots of a polynomial.
- Finding roots of cubic and quartic equations in special cases using elementary symmetric functions.
- Using Cardon's and Descartes' methods, respectively.

Learning Outcomes

After completion of this paper, the students will be able to:

- Understand the nature of the roots of polynomial equations and their symmetries.
- Solve cubic and quartic polynomial equations with special condition on roots and in general.
- Find symmetric functions in terms of the elementary symmetric polynomials.

SYLLABUS OF DSE-1(iii)

Unit – 1 **(18 hours)**

Polynomial Equations and Properties

General properties of polynomials and equations; Fundamental theorem of algebra and its consequences; Theorems on imaginary, integral and rational roots; Descartes' rule of signs for positive and negative roots; Relations between the roots and coefficients of equations, Applications to solution of equations when an additional relation among the roots is given; De Moivre's theorem for rational indices, the *n*th roots of unity and symmetries of the solutions.

Unit – 2 **(12 hours)**

Cubic and Biquadratic (Quartic) Equations

Transformation of equations (multiplication, reciprocal, increase/diminish in the roots by a given quantity), Removal of terms; Cardon's method of solving cubic and Descartes' method of solving biquadratic equations.

Unit – 3 **(15 hours)**

Symmetric Functions

Elementary symmetric functions and symmetric functions of the roots of an equation; Newton's theorem on sums of the like powers of the roots; Computation of symmetric functions such as $\sum\alpha^2\beta,\ \sum\alpha^2\beta^2,\ \sum\alpha^2\beta\gamma,\ \sum\frac{1}{\alpha^2\beta\gamma},\ \sum\alpha^{-3},\ \sum(\beta+\gamma-\alpha)^2,\ \sum\frac{\alpha^2+\beta\gamma}{\beta+\gamma},\ldots$ of polynomial equations; Transformation of equations by symmetric functions and in general.

Essential Readings

1. Burnside, W.S., & Panton, A.W. (1979). The Theory of Equations (11th ed.). Vol. 1. Dover Publications, Inc. (4th Indian reprint. S. Chand & Co. New Delhi).
2. Dickson, Leonard Eugene (2009). First Course in the Theory of Equations. John Wiley & Sons, Inc. The Project Gutenberg eBook: http://www.gutenberg.org/ebooks/29785

Suggestive Readings

- Prasad, Chandrika (2017). Text Book of Algebra and Theory of Equations. Pothishala Pvt Ltd.

Note: Examination scheme and mode shall be as prescribed by the Examination Branch, University of Delhi, from time to time.

COMMON POOL OF GENERIC ELECTIVES (GE) COURSES OFFERED BY DEPARTMENT OF MATHEMATICS
Category-IV

GENERIC ELECTIVES-GE-3(i): DIFFERENTIAL EQUATIONS

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Differential Equations	4	3	1	0	Class XII pass with Mathematics	Nil

Learning Objectives
The primary objective of this course is to introduce:
- Ordinary and partial differential equations.
- Basic theory of higher order linear differential equations, Wronskian and its properties.
- Various techniques to find the solutions of above differential equations which provide a basis to model complex real-world situations.

Learning Outcomes
This course will enable the students to:
- Solve the exact, linear, Bernoulli equations, find orthogonal trajectories and solve rate problems.
- Apply the method of undetermined coefficients and variation of parameters to solve linear differential equations.
- Solve Cauchy-Euler equations and System of linear differential equations.
- Formulate and solve various types of first and second order partial differential equations.

SYLLABUS OF GE-3(i)

Unit – 1 **(15 hours)**

Ordinary Differential Equations

First order ordinary differential equations: Basic concepts and ideas, First order Exact differential equations, Integrating factors and rules to find integrating factors, Linear equations and Bernoulli equations, Initial value problems, Applications of first order differential equations: Orthogonal trajectories and Rate problems; Basic theory of higher order linear differential equations, Wronskian and its properties.

Unit – 2 **(12 hours)**

Explicit Methods of Solving Higher-Order Linear Differential Equations

Linear homogeneous equations with constant coefficients, Linear non-homogeneous equations, Method of undetermined coefficients, Method of variation of parameters, Two-point boundary value problems, Cauchy-Euler equations, System of linear differential equations.

Unit – 3 **(18 hours)**

First and Second Order Partial Differential Equations

Classification and Construction of first-order partial differential equations, Method of characteristics and general solutions of first-order partial differential equations, Canonical forms and method of separation of variables for first order partial differential equations; Classification and reduction to canonical forms of second-order linear partial differential equations and their general solutions.

Essential Readings

1. Myint-U, Tyn and Debnath, Lokenath (2007). Linear Partial Differential Equations for Scientist and Engineers (4th ed.). Birkhäuser. Indian Reprint.
2. Ross, Shepley L. (1984). Differential Equations (3rd ed.). John Wiley & Sons.

Suggestive Readings

- Edwards, C. Henry, Penney, David E., & Calvis, David T. (2015). Differential Equations and Boundary Value Problems: Computing and Modeling (5th ed.). Pearson Education.
- Kreyszig, Erwin. (2011). Advanced Engineering Mathematics (10th ed.). Wiley India.
- Sneddon I. N. (2006). Elements of Partial Differential Equations. Dover Publications.

GENERIC ELECTIVES-GE-3(ii): LATTICES AND NUMBER THEORY

CREDIT DISTRIBUTION, ELIGIBILITY AND PRE-REQUISITES OF THE COURSE

Course title & Code	Credits	Credit distribution of the course			Eligibility criteria	Pre-requisite of the course (if any)
		Lecture	Tutorial	Practical/ Practice		
Lattices and Number Theory	4	3	1	0	Class XII pass with Mathematics	Nil

Learning Objectives

The primary objective of this course is to introduce:

- The concepts of ordered sets, lattices, sublattices and homomorphisms between lattices.
- Distributive lattices along with Boolean algebra and their applications in the real-world.
- Divisibility theory of congruences along with some applications.
- The number-theoretic functions and quadratic reciprocity law.

Learning Outcomes

This course will enable the students to:

- Understand the notion of ordered sets. Learn about lattices, distributive lattices, sublattices and homomorphisms between lattices.
- Become familiar with Boolean algebra, Boolean polynomials, switching circuits and their applications.
- Learn the concept of Karnaugh diagrams and Quinn–McCluskey method which gives an aid to apply truth tables in real-world problems.

- Learn about some fascinating properties of prime numbers, and some of the open problems in number theory, viz., Goldbach conjecture etc.
- Know about modular arithmetic and number-theoretic functions like Euler's Phi-function.
- Find quadratic residues and nonresidues modulo primes using Gauss's Quadratic Reciprocity Law.

SYLLABUS OF GE-3(ii)

Unit – 1

Partially Ordered Sets and Lattices **(21 hours)**

Definitions, Examples and basic properties of partially ordered sets, Order isomorphism, Hasse Diagram, Maximal and minimal elements, Dual of an ordered set, Duality principle; Statements of Well Ordering Principle and Zorn's Lemma; Lattices as ordered sets, Lattices as algebraic structures, Sublattices, Products and homomorphisms, Distributive lattices, Boolean algebras, Boolean polynomials, Minimal forms of Boolean polynomials, Quinn-McCluskey method, Karnaugh diagrams, Switching circuits and applications.

Unit – 2

Divisibility and Theory of Congruences **(12 hours)**

The division algorithm: GCD, The Euclidean algorithm, Diophantine equation $ax + by = c$
Primes: The Fundamental Theorem of Arithmetic, Infinitude of primes, Twin primes and Goldbach conjecture.
The theory of congruences: Basic properties and applications, Linear congruences and the Chinese Remainder Theorem, Fermat's Little Theorem and Wilson's Theorem.

Unit – 3

Number-Theoretic Functions, Primitive roots and Quadratic Reciprocity Law **(12 hours)**

Number-Theoretic Functions: Sum and number of divisors, Euler's Phi-function and Euler's generalization of Fermat's Little Theorem.
Primitive roots: The order of an integer modulo n, and primitive roots of an integer.
Quadratic Reciprocity Law: Quadratic residue and nonresidue, Euler's Criterion, The Legendre symbol and its properties and Quadratic Reciprocity Law.

Essential Readings

1. Davey, B A., & Priestley, H. A. (2002). Introduction to Lattices and Order (2nd ed.), Cambridge University Press, Cambridge.
2. Lidl, Rudolf & Pilz, Günter. (1998). Applied Abstract Algebra (2nd ed.), Undergraduate Texts in Mathematics, Springer (SIE), Indian Reprint 2004.
3. Burton, David M. (2012). Elementary Number Theory (7th ed.), Mc-Graw Hill Education Pvt. Ltd. Indian Reprint.

Suggestive Readings

- Rosen, Kenneth H. (2019). Discrete Mathematics and its Applications (8th ed.), Indian adaptation by Kamala Krithivasan. McGraw-Hill Education. Indian Reprint 2021.
- Goodaire, Edgar G., & Parmenter, Michael M. (2006). Discrete Mathematics with Graph Theory (3rd ed.). Pearson Education Pvt. Ltd. Indian Reprint 2018.
- Jones, G. A., & Jones, J. Mary. (2005). Elementary Number Theory. Springer Undergraduate Mathematics Series (SUMS). Indian Reprint.

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