**Three-year B.Sc. in**

# Mathematics

(Honours)

under

CBCS

System

# Graduate Attributes in Mathematics

The aspiring mathematician embarks on a journey woven from logic, proof, and the boundless beauty of numbers. As they progress, they cultivate a unique set of attributes, becoming not just masters of calculation, but architects of knowledge and contributors to the advancement of science and society.

1. **Disciplinary Expertise:** A deep understanding of the fundamental concepts, theories, and techniques across various subfields of mathematics forms the bedrock of their intellectual prowess. From abstract number theory to real-world applications in optimization and modeling, their knowledge empowers them to tackle diverse challenges with clarity and rigor.
2. **Algorithmic Architects:** They wield algorithms as tools, constructing computational solutions to complex problems. Be it optimizing financial models, forecasting weather patterns, or deciphering the inner workings of physical systems, their fluency in the language of algorithms equips them to bridge the gap between theory and practice.
3. **Crystal Clear Communicator:** The arcane language of mathematics becomes transparent in their articulation. They translate complex concepts into clear and concise explanations, fostering collaboration and nurturing the next generation of mathematical talent.
4. **Critical Problem Solver:** Faced with an enigmatic mathematical puzzle, their mind delves into a tapestry of logical deduction. They dissect assumptions, forge elegant solutions, and navigate intricate complexities with unwavering persistence.
5. **Inquiry Weaver:** A burning curiosity propels them forward. They craft insightful questions that challenge established paradigms and pave the way for groundbreaking discoveries. They meticulously conduct proofs, present their findings with conviction, and contribute to the ever-evolving dialogue of mathematical inquiry.
6. **Collaborative Virtuoso:** The spirit of teamwork flourishes in diverse mathematical ensembles. They seamlessly integrate their expertise, learn from fellow explorers, and cultivate a synergistic environment where knowledge thrives.
7. **Project Maestro:** Orchestrating research projects becomes an art form. They identify crucial resources, map strategic pathways, and navigate challenges with meticulous planning and unwavering ethical conduct.

8. **Digital Wizardry:** The computer becomes their laboratory, where algorithms paint vibrant landscapes of data. They wield advanced computational tools with mastery, transforming raw numbers into profound insights and unraveling the hidden patterns within.
9. **Ethical Architect:** Integrity becomes the cornerstone of their work. They identify and navigate ethical dilemmas with transparency and fairness, upholding the highest standards of academic conduct and intellectual property.

10. **Global Citizen:** Their perspective transcends borders, embracing a deep understanding of the international landscape of mathematics. They see their contributions as threads woven into the global tapestry of scientific progress, driving advancements for the betterment of humanity.
11. **Lifelong Learner:** The quest for knowledge knows no bounds. They remain self-directed learners, constantly seeking new avenues to refine their skills, update their knowledge, and reshape their expertise. The journey through the boundless world of mathematics is a lifelong pursuit, fueled by unwavering dedication and a boundless passion for exploration.

These attributes paint a portrait of a graduate mathematician poised to make a significant impact on the world. They are not just skilled technicians, but architects of knowledge, collaborators, and leaders in the pursuit of understanding the very fabric of reality through the lens of mathematics.

# Program Learning Outcomes (POs) in a B.Sc. (Honours) Mathematics

Program Learning Outcomes (POs) in a Bachelor of Science (Honours) Mathematics program outline the specific knowledge, skills, and abilities that students are expected to acquire by the end of their studies. These outcomes reflect the overall goals of the program and serve as a guide for curriculum development and assessment. Here are some key Program Learning Outcomes for a B.Sc (Honours) Mathematics program:

1. **Mathematical Knowledge and Understanding:** Graduates should demonstrate a comprehensive understanding of foundational mathematical concepts, theories, and principles across various branches of mathematics, including but not limited to algebra, calculus, analysis, geometry, and discrete mathematics.
2. **Problem-Solving Proficiency:** Graduates should be proficient in applying mathematical techniques to solve complex problems. This involves the ability to analyze problems, formulate mathematical models, and apply appropriate methods for solution.
3. **Mathematical Reasoning and Proof:** Graduates should possess strong mathematical reasoning skills and be able to construct rigorous mathematical proofs. This includes understanding the logical structure of mathematical arguments and the ability to communicate proofs effectively.
4. **Advanced Calculus and Analysis:** Graduates should have a deep understanding of advanced calculus and mathematical analysis, including the convergence of sequences and series, limits, continuity, and the fundamental theorems of calculus.
5. **Algebraic Structures:** Graduates should be familiar with algebraic structures such as groups, rings, and fields, and be able to apply abstract algebraic concepts to various mathematical problems.
6. **Geometry and Topology:** Graduates should have a solid understanding of geometry and topology, including concepts such as symmetry, transformations, and the properties of geometric shapes.
7. **Applied Mathematics:** Graduates should be able to apply mathematical techniques to real-world problems in various scientific and engineering domains. This includes proficiency in mathematical modeling, data analysis, and numerical methods.
8. **Mathematical Software and Technology:** Graduates should be proficient in using mathematical software and technology to aid in problem-solving, visualization, and data analysis.

9. **Effective Communication:** Graduates should be able to communicate mathematical ideas clearly and effectively, both in written and oral forms, to diverse audiences, including peers and non-specialists.
10. **Independent Research Skills:** Graduates should demonstrate the ability to conduct independent research in mathematics. This includes formulating research questions, conducting literature reviews, and applying appropriate research methodologies.
11. **Ethical and Professional Conduct:** Graduates should adhere to ethical standards in mathematical research and practice, including proper citation of sources, integrity in data analysis, and responsible use of mathematical knowledge.
12. **Lifelong Learning:** Graduates should recognize the importance of lifelong learning in mathematics, staying abreast of new developments in the field, and continuously enhancing their mathematical skills and knowledge.

These Program Learning Outcomes collectively ensure that graduates of the B.Sc (Honours) Mathematics program are well-prepared for a variety of career paths, including further study at the graduate level or employment in fields requiring strong analytical and mathematical skills.

# Core Course for B.Sc Mathematics (Hons.)

| S. No. | POs | CC - 1 | CC - 2 | CC - 3 | CC - 4 | CC - 5 | CC - 6 | CC - 7 | CC - 8 | CC-9 | CC-10 | CC - 11 | CC - 12 | CC-13 | CC-14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Fundamental understanding of the field | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| 2 | Application of basic Mathematics concepts | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| 3 | Linkages with related disciplines | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| 4 | Procedural knowledge for professional subjects | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| 5 | Skills in related field of specialization | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| 6 | Ability to use in Mathematics problem | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| 7 | Skills in Mathematical modeling | ✔ | ✔ | ✔ | ✔ | ✔ | _ | _ | ✔ | _ | ✔ | ✔ | ✔ | _ | ✔ |
| 8 | Skills in performing analysis and interpretation of data | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| 9 | Develop investigative Skills | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | _ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| 10 | Skills in problem solving in Mathematics and related discipline | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| 11 | Develop Technical Communication skills | ✔ | ✔ | ✔ | ✔ | - | - | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| 12 | Developing analytical skills and popular communication | ✔ | ✔ | ✔ | ✔ | - | - | ✔ | - | _ | _ | ✔ | ✔ | - | ✔ |
| 13 | Developing ICT skills | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | _ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| 14 | Demonstrate professional behaviour with respect to attribute like objectivity, ethical values, self reading, etc | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |

## Discipline Specific Electives (DSE) and

## Skill Enhancement Course (SEC) for B.Sc. Mathematics (Hons.)

| Sl. No | POs | DSE A 1.1 | DSE A 1.2 | DSE B 1.2 | DSE A 2.2 | DSE B 2.3 | SEC A 1.1 | SEC B 1.2 |
|---|---|---|---|---|---|---|---|---|
| 1 | Fundamental understanding of the field | ✔ | ✔ | ✔ | ✔ | ✔ | | |
| 2 | Application of basic Mathematical concepts | ✔ | ✔ | ✔ | ✔ | ✔ | | |
| 3 | Linkages with related disciplines | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| 4 | Procedural knowledge for professional subjects | - | - | - | - | - | ✔ | ✔ |
| 5 | Skills in related field of specialization | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| 6 | Ability to use in Mathematics problem | ✔ | ✔ | ✔ | ✔ | ✔ | - | ✔ |
| 7 | Skills in Mathematical modeling | - | - | - | - | - | - | - |
| 8 | Skills in performing analysis and interpretation of data | - | - | - | - | - | - | ✔ |
| 9 | Develop investigative Skills | - | - | - | - | - | - | ✔ |
| 10 | Skills in problem solving in Mathematics and related discipline | ✔ | ✔ | ✔ | ✔ | ✔ | - | - |
| 11 | Develop Technical Communication skills | - | - | - | - | - | ✔ | ✔ |
| 12 | Developing analytical skills and popular communication | - | - | - | - | - | ✔ | ✔ |
| 13 | Developing ICT skills | - | - | - | - | - | ✔ | ✔ |
| 14 | Demonstrate Professional behaviour with respect to attribute like objectivity, ethical values, self-reading, etc | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |

# Course Learning Outcomes (CLO)

## Core Courses (CC)

### CC1: Calculus, Geometry & Vector Analysis
### (Credits: 06, Theory-05, Tutorial-01)

#### Course learning outcome (COs):

Upon successful completion of this course, students will be able to:

**Calculus:**

1. Apply knowledge of hyperbolic functions, higher-order derivatives, and Leibnitz rule to solve problems involving exponential, trigonometric, and polynomial functions.
2. Analyze curves using curvature, concavity, points of inflection, envelopes, and asymptotes, both in Cartesian and parametric forms.
3. Trace curves in Cartesian and polar coordinates, including standard curves.
4. Utilize L'Hospital's rule to determine indeterminate forms.
5. Solve application problems in business, economics, and life sciences using calculus concepts.
6. Derive and apply reduction formulae for integrals of various forms.
7. Parametrize curves, calculate arc length (including for parametric curves), and determine the area under a curve.
8. Calculate the area and volume of the surfaces of revolution.

**Geometry:**

1. Classify second-degree equations and conics using the discriminant and derive equations for tangents and normals.
2. Write equations for planes in various forms, calculate distances from points to planes, and determine angles between planes.
3. Represent and analyze lines in 3D using parametric and symmetric equations, direction ratios/cosines, and intersection with planes.
4. Solve problems involving spheres, cylindrical surfaces, and central conicoids (paraboloids, ellipsoids, hyperboloids).
5. Classify quadric surfaces and visualize standard forms like cones and ellipsoids.
6. Derive equations for tangents and normals of conicoids.

**Vector Analysis:**

1. Perform triple products, solve vector equations, and apply vector analysis to problems in geometry and mechanics, including concurrent forces, couples, and parallel forces.
2. Understand and perform operations with vector-valued functions, including limits, continuity, differentiation, and integration.

**Graphical Demonstration:**

1. Plot and analyze graphs of various functions, polynomial functions, and their derivatives. Sketch parametric curves and surfaces o f revolution.
2. Trace conics in both Cartesian and polar coordinates.
3. Sketch quadric surfaces (ellipsoids, hyperboloids, paraboloids) using Cartesian coordinates.

**Additionally, students will**

1. Develop problem-solving skills and critical thinking abilities.
2. Improve their communication skills through written and graphical representation of mathematical concepts.
3. Appreciate the connections between mathematics and other fields, such as Mathematics, engineering, and economics.

# CC2: Algebra
# (Credits: 06, Theory-05, Tutorial-01)

## Course learning outcome (COs):

Upon successful completion of this course, students will be able to:

**Complex Numbers:**

- Navigate the complex plane using polar representation, including finding n-th roots of unity and applying De Moivre's theorem to solve problems.
- Master advanced functions of a complex variable, including exponential, logarithmic, trigonometric, and hyperbolic functions.
- Analyze and solve problems involving theory of equations, utilizing techniques like Descartes' rule of signs, Sturm's theorem, and solution methods for specific equations like cubic and biquadratic.
- Gain understanding and employ key inequalities like AM-GM and Cauchy-Schwartz inequality in problem-solving contexts.
- Analyze and solve linear difference equations with constant coefficients up to the second order.

**Relations and Mappings:**

- Differentiate and apply various types of relations, including equivalence relations, partial order relations, and linear order relations.
- Comprehend and utilize concepts around mappings, including injectivity, surjectivity, invertibility, composition, and their relationships with set operations.
- Analyze and interpret the preimage f^(-1)(B) for any function f and subset B of the codomain.

**Number Theory and Matrices:**

- Apply the well-ordering property of integers and principles of mathematical induction to prove theorems and solve problems.
- Utilize the division algorithm and Euclidean algorithm to understand divisibility and find greatest common divisors of integers.
- Grasp the properties and significance of prime numbers, applying Euclid's theorem and the Fundamental Theorem of Arithmetic.
- Analyze and employ the Chinese remainder theorem for solving systems of congruences.
- Understand and utilize key arithmetic functions like phi (totient function), sigma (sum-of-divisors function), and tau (number of divisors function) in various contexts.

- Calculate the rank and inverse of matrices, applying characterizations of invertible matrices to solve related problems.
- Solve systems of linear equations using row reduction and echelon forms, representing solutions with vector equations and the matrix equation $Ax = B$.
- Apply linear systems to real-world scenarios and appreciate their diverse applications.

**Additionally, students will:**

- Develop strong problem-solving skills and critical thinking abilities within the realm of complex numbers, relations, and matrices.
- Enhance their communication skills by effectively demonstrating mathematical concepts verbally and through written representation.
- Gain a deeper appreciation for the interconnectedness of different areas of mathematics and their relevance to various fields of study.

This course will equip students with a diverse set of mathematical tools and problem-solving skills, preparing them for further theoretical endeavors and practical applications in numerous disciplines.

# CC3: Real Analysis
# (Credits: 06, Theory-05, Tutorial-01)

## Course learning outcome (COs):

Upon successful completion of this course, students will be able to:

### Understanding Real Numbers:

- Develop a deep understanding of the intuitive idea of real numbers and their fundamental properties (closure, commutativity, etc.).
- Differentiate between countable and uncountable sets, recognizing the uncountability of real numbers.
- Grasp the concepts of bounded and unbounded sets, supreme/infimum (supremum/infimum), and their properties.
- Comprehend the significance of the L.U.B. axiom and Archimedean property in building the completeness of real numbers.
- Analyze the density of rational and irrational numbers within the real number system.
- Understand and work with intervals, neighborhoods, and different types of sets (open, closed, etc.).
- Apply Bolzano-Weierstrass theorem to identify limit points and closed sets.

### Mastering Real Sequences:

- Define and analyze real sequences, differentiating between bounded and convergent sequences.
- Recognize the relationship between limit points of sets and limits of convergent sequences.
- Work with monotone sequences, applying the sandwich rule and nested interval theorem.
- Calculate and understand the limits of various important sequences, including harmonic series, geometric series, and recursive sequences.
- Employ Cauchy's first and second limit theorems to establish convergence.
- Identify subsequences and subsequential limits using both theoretical and graphical approaches.
- Utilize Bolzano-Weierstrass theorem and Cauchy's convergence criterion to determine convergence of sequences.

### Exploring Infinite Series:

- Define and distinguish between convergent and non-convergent infinite series.
- Apply Cauchy's criterion to test for convergence.
- Master various convergence tests, including comparison, limit comparison, ratio, Cauchy's n-th root, Kummer's, and Gauss's tests (statements only).
- Analyze alternating series using the Leibniz test.
- Differentiate between absolute and conditional convergence.

### Graphical Demonstrations:

- Utilize computer software or manual plotting techniques to visualize the behavior of recursive sequences and their convergence/divergence.
- Apply graphical methods to verify Bolzano-Weierstrass theorem and identify subsequential limits.
- Analyze the convergence/divergence of infinite series by plotting their sequences of partial sums.
- Gain deeper understanding of convergence tests like Cauchy's root and ratio tests through graphical representations.

### Additionally, students will:

- Develop strong problem-solving skills and critical thinking abilities within the context of real numbers and sequences.
- Enhance their communication skills by effectively demonstrating mathematical concepts both verbally and visually.
- Appreciate the theoretical elegance and practical applications of real analysis in various fields of science and engineering.

This course will equip students with a powerful understanding of real numbers and sequences, providing them with a solid foundation for further exploration in advanced mathematics and related disciplines. The combination of theoretical rigor and graphical demonstrations will foster a deeper appreciation for the beauty and complexity of real analysis.

# CC4: Group Theory - I

# (Credits: 06, Theory-05, Tutorial-01)

## Course learning outcome (COs):

Upon successful completion of this course, students will be able to:

**Understanding Symmetries and Groups:**

- Analyze symmetries of geometric shapes like squares and understand their connection to group structures.
- Define and recognize examples of various types of groups, including permutation groups, dihedral groups, and quaternion groups (represented by matrices).
- Comprehend the fundamental properties of groups, including closure, associativity, identity, and inverses.
- Differentiate between commutative and non-commutative groups and provide examples of each.
- Identify and analyze subgroups within a group, applying necessary and sufficient conditions for their existence.
- Define and calculate the normalizers, centralizers, and centers of a group.
- Understand the concept of the product of subgroups and its properties.

**Delving into Cyclic Groups and Permutations:**

- Master the properties of cyclic groups and develop methods for classifying their subgroups.
- Utilize cycle notation to represent permutations and analyze their properties.
- Differentiate between even and odd permutations and understand the structure of the alternating group.
- Analyze the concept of cosets and calculate the order of elements and groups.
- Apply Lagrange's theorem and its consequences, including Fermat's Little theorem, to solve problems related to group order.

**Exploring Normal Subgroups and Homomorphisms:**

- Define and work with normal subgroups, understanding their unique properties.
- Construct and analyze quotient groups derived from normal subgroups.
- Master the concept of group homomorphisms and demonstrate their key properties.
- Apply the correspondence theorem to establish a one-to-one correspondence between normal subgroups and congruences on a group.
- Comprehend and utilize Cayley's theorem to represent groups as permutation groups.
- Analyze the properties of isomorphisms and apply the first, second, and third isomorphism theorems to solve problems related to group structure.

**Additionally, students will:**

- Develop strong problem-solving skills and critical thinking abilities within the context of group theory.
- Enhance their communication skills by effectively explaining and illustrating abstract concepts of group theory.
- Appreciate the connections between group theory and diverse fields like abstract algebra, cryptography, and crystallography.
- Gain a strong foundation for further exploration in advanced mathematics and related disciplines.

This course will equip students with a powerful understanding of groups and their properties, empowering them to analyze symmetries, solve problems related to order and structure, and appreciate the elegance and diverse applications of group theory in various fields.

# CC5: Theory of Real Functions

# (Credits: 06, Theory-05, Tutorial-01)

## Course Outcomes:

Upon successful completion of this course, students will be able to:

### Limits and Continuity

- Grasp the concept of limits, employing both the epsilon-delta approach and sequential criteria.
- Apply algebra of limits to evaluate the limits of complex expressions and understand the effect of limits on inequalities.
- Calculate one-sided limits, infinite limits, and limits at infinity.
- Determine continuity of functions on intervals and at isolated points, using sequential criteria and oscillation concepts.
- Recognize and visualize graphs of common functions like powers, absolute value, trigonometric, logarithmic, and exponential functions.
- Demonstrate algebra of continuous functions and continuity of composite functions.
- Understand boundedness properties of continuous functions and apply the Intermediate Value Theorem.
- Classify types of discontinuities (jump, removable, infinite), and analyze step and piecewise continuous functions.
- Work with monotone functions, recognizing their properties and relationship to continuity.
- Define and apply uniform continuity, understanding its relationship to bounded and unbounded intervals.

### Differentiability

- Define differentiability of functions at a point and over intervals, and apply algebra of differentiable functions.
- Interpret the sign of the derivative in terms of function behavior.
- Utilize the chain rule to differentiate composite functions.
- Prove and apply Darboux's theorem, Rolle's theorem, and the mean value theorems of Lagrange and Cauchy.
- Formulate Taylor's theorem on closed and bounded intervals, deriving Lagrange's and Cauchy's forms of the remainder.
- Expand exponential, logarithmic, power, sine, and cosine functions using Taylor series, understanding their range of validity.
- Apply Taylor's theorem to establish inequalities.

- Apply L'Hôpital's rule to evaluate limits of indeterminate forms.
- Identify and classify local extrema (maxima and minima) of functions using first-order derivatives.
- Solve geometrical problems involving maxima and minima, applying optimization principles.

**Additionally, students will:**

- Develop strong problem-solving skills and critical thinking abilities within the context of limits, continuity, and differentiability.
- Enhance their communication skills by effectively explaining and illustrating these concepts, both verbally and graphically.
- Gain a solid foundation for further exploration in calculus, analysis, and related fields.

# CC6: Ring Theory & Linear Algebra-I

# (Credits: 06, Theory-05, Tutorial-01)

## Course Outcomes:

Upon successful completion of this course, students will be able to:

### Ring Theory

- Define and recognize various types of rings, including their properties, examples, and necessary and sufficient conditions for subrings and subfields.
- Understand the characteristic of a ring and its implications.
- Work with ideals, including generating ideals, factor rings, operations on ideals, and identifying prime and maximal ideals.
- Define and apply ring homomorphisms, using their properties to establish relationships between rings.
- Apply the first, second, and third isomorphism theorems to prove structural properties of rings.
- Understand the correspondence between ideals and congruences on rings, enabling alternative perspectives on ring structure.

### Linear Algebra

- Define and work with vector spaces, subspaces, and quotient spaces, understanding their interplay and algebraic properties.
- Calculate linear combinations, spans, and linear independence of vectors, and determine bases and dimensions of vector spaces.
- Analyze subspaces of R^n, calculating their dimensions and recognizing their geometric significance.
- Define and apply linear transformations, calculating null spaces, ranges, ranks, and nullities.
- Represent linear transformations using matrices and change of coordinate matrices, understanding their connections.
- Examine algebra of linear transformations, including isomorphisms and their relationships to invertibility.
- Calculate eigenvalues and eigenvectors of matrices, formulating characteristic equations.
- Apply the Cayley-Hamilton theorem to find inverses of matrices and solve related problems.

### Additionally, students will:

- Develop strong problem-solving skills and critical thinking abilities within the context of abstract algebra and linear algebra.
- Enhance their communication skills by effectively explaining and illustrating abstract concepts, both verbally and symbolically.
- Gain a solid foundation for further exploration in abstract algebra, linear algebra, and related fields, such as number theory, analysis, and applied mathematics.

# CC7: Ordinary Differential Equation & Multivariate Calculus-I

# (Credits: 06, Theory-05, Tutorial-01)

## Course Outcomes:

Upon successful completion of this course, students will be able to:

### Ordinary Differential Equations

- Solve first-order differential equations using integrating factors, linear equations, Bernoulli equations, and transformations.
- Apply existence and uniqueness theorems to understand the behavior of solutions.
- Analyze linear systems of differential equations, including homogeneous linear systems with constant coefficients.
- Solve second-order linear differential equations using Wronskians, Euler equations, undetermined coefficients, and variation of parameters.
- Work with systems of linear differential equations, employing differential operators and operator methods.
- Analyze planar linear autonomous systems, identifying equilibrium points and interpreting phase planes and portraits.
- Apply power series methods for finding approximate solutions to differential equations, around ordinary and regular singular points.

### Multivariate Calculus I

- Understand fundamental concepts of topology in R^n, including neighborhoods, interior points, limit points, open sets, and closed sets.
- Define and analyze functions from R^n to R^m, exploring limits and continuity in multiple dimensions.
- Calculate partial derivatives, total derivatives, and gradients of multivariable functions.
- Apply the chain rule for multiple independent parameters and utilize directional derivatives to analyze function behavior.
- Find extrema of functions of two variables using the gradient and Lagrange multipliers, and solve constrained optimization problems.

**Additionally, students will:**

- Develop strong problem-solving skills and critical thinking abilities within the context of differential equations and multivariate calculus.
- Enhance their ability to model real-world phenomena using differential equations, making predictions, and drawing insights.
- Gain a solid foundation for further exploration in differential equations, calculus, analysis, and applied mathematics, preparing them for advanced courses in physics, engineering, and other quantitative fields.

# CC8: Riemann Integration & Series of Functions

## (Credits: 06, Theory-05, Tutorial-01)

## Course Outcomes:

Upon successful completion of this course, students will be able to:

### Riemann Integration

- Define partitions, refinements, upper and lower Darboux sums, upper and lower integrals, and Darboux's theorem.
- Master the concepts of Riemann and Darboux integrability, understanding their equivalence and necessary and sufficient conditions.
- Recognize negligible sets and their properties, and apply them to determine integrability.
- Prove and apply properties of Riemann integrable functions, including integrability of sums, scalar multiples, products, quotients, and moduli.
- Define definite integrals, antiderivatives, and the logarithmic function as a definite integral, and explore their properties.
- Understand and apply the Fundamental Theorem of Calculus and the First Mean Value Theorem of Integral Calculus.

### Improper Integrals

- Evaluate improper integrals with finite and infinite ranges of integration, understanding their convergence criteria.
- Apply comparison and M-tests for convergence, distinguish between absolute and non-absolute convergence, and apply Abel's and Dirichlet's tests for integrals of products.
- Work with Beta and Gamma functions, compute their values, and apply them to evaluate integrals involving trigonometric functions.

### Series of Functions

- Define pointwise and uniform convergence of sequences and series of functions, and apply Cauchy's criterion and Weierstrass' M-test for uniform convergence.
- Understand the behavior of limit functions in terms of boundedness, continuity, integrability, and differentiability under uniform convergence.
- Explore power series, applying Cauchy-Hadamard theorem to determine radius of convergence, and examine uniform and absolute convergence, properties of sum functions, differentiation, integration, and Abel's limit theorems.
- Introduce Fourier series, trigonometric series, Fourier coefficients for periodic functions, Dirichlet's condition of convergence, and the theorem of the sum of Fourier series.

**Additionally, students will:**

- Develop strong analytical and problem-solving skills within the context of integration and series of functions.
- Enhance their ability to construct rigorous mathematical arguments and proofs.
- Gain a solid foundation for further exploration in advanced calculus, real analysis, and related fields, including potential applications in physics, engineering, and other quantitative disciplines.

# CC9: Partial differential equation & Multivariate Calculus-II

## (Credits: 06, Theory-05, Tutorial-01)

## Course Outcomes:

Upon successful completion of this course, students will be able to:

### Partial Differential Equations

- Solve first-order partial differential equations using Lagrange's method and Charpit's method, and recognize special cases amenable to simpler techniques.
- Derive and classify fundamental partial differential equations, including heat, wave, and Laplace equations, as hyperbolic, parabolic, or elliptic.
- Reduce second-order linear partial differential equations to canonical forms.
- Solve Cauchy problems for finite and infinite strings, as well as initial boundary value problems for semi-infinite strings with fixed and free ends.
- Apply the method of separation of variables to solve vibrating string and heat conduction problems.

### Multivariate Calculus II

- Define and evaluate multiple integrals, including double and triple integrals, using iterated integrals and changing the order of integration.
- Work with cylindrical and spherical coordinates, and apply change of variables to transform integrals.
- Calculate volumes and surface areas using multiple integrals.
- Define vector fields, divergence, and curl, and evaluate line integrals with applications to mass and work.
- Understand conservative vector fields and the Fundamental Theorem for Line Integrals.
- Apply Green's theorem, evaluate surface integrals over parametrically defined surfaces, and employ Stokes' theorem and the Divergence theorem.

### Additionally, students will:

- Develop strong problem-solving skills within the context of partial differential equations and multivariate calculus.
- Enhance their ability to model and analyze physical phenomena using partial differential equations, making predictions and drawing insights.
- Gain a solid foundation for further exploration in advanced calculus, differential equations, analysis, and applied mathematics, preparing them for studies in physics, engineering, and other quantitative fields.

# CC10: Mechanics
# (Credits: 06, Theory-05, Tutorial-01)

## Course Outcomes:

Upon successful completion of this course, students will be able to:

### Statics

- Analyze and manipulate coplanar forces, calculating resultant forces and couples, applying Varignon's theorem, and determining equilibrium conditions.
- Extend these concepts to three-dimensional force systems, calculating moments of force, finding resultant forces and couples, and establishing equilibrium conditions using various methods, including reduction to a wrench and Poinsot's central axis.
- Understand the role of friction in equilibrium problems, applying Coulomb's laws to static and dynamic friction, interpreting friction angles and cones, and defining the equilibrium region.
- Solve statically determinate and indeterminate problems involving forces and equilibrium.

**Mechanics**

- Apply the principle of virtual work to analyze systems with workless constraints, calculate virtual displacements and virtual work, and derive the necessary and sufficient conditions for equilibrium of arbitrary force systems in both planes and space.
- Assess the stability of equilibrium using the energy test, determine stability conditions for specific cases like a perfectly rough heavy body on a fixed surface, and analyze the behavior of rocking stones.

### Kinematics and Dynamics

- Analyze the motion of particles using concepts like velocity, acceleration, angular velocity, linear and angular momentum, and relative motion.
- Calculate displacement, velocity, and acceleration for rectilinear and planar motion in both Cartesian and polar coordinates, differentiating between tangential and normal components.
- Understand the principles of uniform circular motion and its mathematical representation.
- Apply Newton's laws of motion and the law of gravitation to solve problems involving forces, motion, and energy in various contexts.
- Define and utilize concepts like work, power, kinetic energy, and potential energy, identifying conservative forces and the existence of potential energy functions.
- Apply the principle of energy conservation in conservative systems and analyze the stability of equilibrium using the energy test.

- Solve various particle dynamics problems, including those involving rectilinear motion under different force fields (including gravity and inverse square law), constrained motion, damped and forced oscillations, and motion of elastic strings and springs.

**Advanced Particle Dynamics**

- Analyze the motion of projectiles in a resisting medium and under gravity, understanding trajectories and stability of nearly circular orbits.
- Apply Kepler's laws to study planetary motion and analyze the behavior of slightly disturbed orbits and artificial satellites.
- Solve problems involving the motion of particles on smooth and rough curves, including those with rotating axes.
- Extend particle dynamics concepts to three dimensions, analyzing motion on surfaces like spheres, cones, and surfaces of revolution.

**Mechanics of Many-Particle Systems**

- Understand the concept of linear momentum and the principle of linear momentum conservation, applying it to analyze the motion of the center of mass in multi-particle systems.
- Define and calculate the moment of a force and angular momentum about a point and an axis, applying the principle of angular momentum conservation to solve problems involving impulsive forces.
- Analyze multi-particle systems using the energy principle, considering configurations, degrees of freedom, and energy conservation.
- Solve problems involving rocket motion in free space and under gravity, collisions of elastic bodies, and the two-body problem.

**Overall Course Outcomes:**

- Develop a strong foundation in mathematical mechanics, including statics, kinematics, dynamics, and mechanics of many-particle systems.
- Apply mathematical principles to solve real-world problems involving forces, motion, energy, and momentum.
- Utilize analytical and problem-solving skills to analyze complex mechanical systems and predict their behavior.
- Gain familiarity with key concepts and tools in classical mechanics, preparing for further studies in physics, engineering, and related fields.

# CC11: Probability & Statistics

## (Credits: 06, Theory-05, Tutorial-01)

## Course Outcomes:

Upon successful completion of this course, students will be able to:

### Foundations of Probability

- Establish a solid understanding of probability concepts, including random experiments, sample spaces, probability axioms, probability spaces, conditional probability, Bayes theorem, and independence.
- Distinguish between discrete and continuous random variables, and work with cumulative distribution functions, probability mass/density functions, mathematical expectation, moments, moment generating functions, and characteristic functions.
- Apply probability distributions to real-world problems, including uniform, binomial, Poisson, geometric, negative binomial, continuous uniform, normal, and exponential distributions.

### Joint Distributions and Regression

- Analyze joint distributions of two random variables using joint cumulative distribution functions, joint probability density functions, marginal and conditional distributions, and expectation of functions of two random variables.
- Calculate covariance, correlation coefficients, and determine the independence of random variables.
- Work with joint moment generating functions and characteristic functions to derive properties of joint distributions.
- Apply linear regression to model relationships between two variables and create regression curves.
- Understand the bivariate normal distribution and its properties.

### Convergence and Limit Theorems

- Explore inequalities for probabilities, including Markov and Chebyshev's inequalities.
- Understand the concepts of convergence in probability, weak law of large numbers, and strong law of large numbers, and interpret their implications.
- Apply the central limit theorem to analyze the behavior of sums of independent and identically distributed random variables with finite variance, and understand its importance in statistical inference.

**Sampling and Estimation**

- Understand the concepts of populations, samples, random sampling, and sample characteristics.
- Work with sampling distributions, including those of important statistics like the sample mean, sample variance, and proportions.
- Apply the central limit theorem to approximate sampling distributions and make inferences about populations.
- Estimate population parameters using point and interval estimation techniques, and understand the properties of good estimators.
- Apply the method of maximum likelihood to estimate parameters for various probability models.

**Hypothesis Testing and Bivariate Data**

- Formulate and test statistical hypotheses, distinguishing between simple and composite hypotheses, null and alternative hypotheses, and one-sided and two-sided tests.
- Understand the concepts of critical regions, test statistics, type I and type II errors, level of significance, and power of a test.
- Calculate and interpret p-values for hypothesis tests.
- Apply the Neyman-Pearson lemma to construct most powerful tests for simple hypotheses.
- Analyze bivariate data using scatter diagrams, correlation coefficients, and linear regression.
- Apply the principle of least squares estimation for fitting linear, polynomial, and exponential curves to data.

**Graphical Demonstration (Teaching Aid):**

- Gain hands-on experience with graphical data representation and analysis using statistical software or traditional methods.
- Create and interpret various types of graphs, including histograms, frequency polygons, pie charts, ogives, and scatter plots.
- Calculate and interpret measures of central tendency, dispersion, skewness, and kurtosis.
- Compute and interpret Pearson correlation coefficients for bivariate data.
- Fit lines of regression and estimate values of variables.
- Construct confidence intervals for parameters of normal distributions in one-sample and two-sample problems.

**Overall Course Outcomes:**

- Develop a comprehensive understanding of probability theory and statistical inference.
- Apply probability concepts to model real-world phenomena and analyze data.
- Design and conduct statistical studies, including sampling, estimation, and hypothesis testing.
- Interpret statistical results and draw meaningful conclusions from data.
- Utilize statistical software to visualize and analyze data effectively.
- Gain a solid foundation for further studies in statistics, data analysis, and related fields.

# CC12:Group Theory-II & Linear Algebra-II
# (Credits: 06, Theory-05, Tutorial-01)

## Course Outcomes:

Upon successful completion of this course, students will be able to:

### Group Theory

- Understand automorphisms and inner automorphisms of groups, construct automorphism groups, and apply them to finite and infinite cyclic groups.
- Analyze factor groups and their connections to automorphism groups.
- Construct external direct products of groups and examine their properties.
- Represent the group of units modulo n as an external direct product.
- Understand internal direct products and their applications.
- Apply the converse of Lagrange's theorem and Cauchy's theorem to finite abelian groups.
- Prove and apply the Fundamental Theorem of Finite Abelian Groups.

### Linear Algebra

- Work with inner product spaces, define norms, and apply the Gram-Schmidt orthonormalization process.
- Analyze orthogonal complements and understand Bessel's inequality.
- Define the adjoint of a linear operator and explore its properties.
- Study bilinear and quadratic forms, and diagonalize symmetric matrices.
- Apply the Second Derivative Test to analyze critical points of functions of several variables, and work with Hessian matrices.
- Understand Sylvester's Law of Inertia, index, and signature.
- Construct dual spaces, dual bases, and double duals.
- Calculate the transpose of a linear transformation and its matrix in the dual basis.
- Work with annihilators, eigenspaces, and diagonalizable operators.
- Explore invariant subspaces and apply the Cayley-Hamilton theorem.
- Compute the minimal polynomial for a linear operator and find its canonical forms (Jordan and rational).

**Overall Course Outcomes:**

- Develop a deeper understanding of group theory, exploring automorphisms, direct products, and the structure of finite abelian groups.
- Advance their knowledge of linear algebra, focusing on inner product spaces, adjoints, bilinear forms, quadratic forms, dual spaces, eigenspaces, and canonical forms.
- Apply abstract algebraic concepts to solve problems and prove theorems.
- Strengthen their mathematical problem-solving skills and analytical abilities.
- Prepare for further studies in algebra, abstract algebra, linear algebra, and related fields.

# CC13: Metric Space & Complex Analysis
## (Credits: 06, Theory-05, Tutorial-01)

## Course Outcomes:

Upon successful completion of this course, students will be able to:

### Metric Spaces

- Define metric spaces and provide various examples.
- Work with open sets, closed sets, interior points, closure, boundary, bounded sets, diameter, and distance between sets.
- Understand subspaces of metric spaces.
- Analyze convergent sequences, Cauchy sequences, and completeness properties of metric spaces.
- Apply Cantor's intersection theorem and examine completeness in R and Q.
- Define continuous mappings, characterize continuity using sequences, and explore uniform continuity.
- Work with compactness and sequential compactness, applying the Heine-Borel theorem in R.
- Understand the finite intersection property and behavior of continuous functions on compact sets.
- Define connectedness and provide examples of connected metric spaces, including connected subsets of R and C.
- Study contraction mappings, prove the Banach Fixed Point Theorem, and apply it to solve ordinary differential equations.

### Complex Analysis

- Visualize complex numbers through stereographic projection and identify regions in the complex plane.
- Define limits of complex functions, including limits involving infinity.
- Apply the concept of continuity to functions of a complex variable.
- Compute derivatives of complex functions using differentiation formulas and the Cauchy-Riemann equations.
- Analyze analytic functions, including exponential, logarithmic, trigonometric, hyperbolic functions, and Möbius transformations.
- Work with power series, applying the Cauchy-Hadamard theorem to determine radius of convergence and study uniform and absolute convergence.

- Represent analytic functions using power series and understand their uniqueness properties.
- Define contours and integrate complex functions along contours, estimating moduli of contour integrals.
- State the Cauchy-Goursat theorem and explore its consequences, including the Cauchy integral formula.

**Overall Course Outcomes:**

- Develop a strong foundation in metric spaces and topology, understanding fundamental concepts like open sets, continuity, compactness, and connectedness.
- Acquire a solid understanding of complex analysis, exploring analytic functions, power series, integration, and key theorems like Cauchy-Goursat and Cauchy integral formula.
- Apply abstract mathematical concepts to solve problems and prove theorems in both metric spaces and complex analysis.
- Strengthen mathematical problem-solving skills and analytical abilities in these areas.
- Prepare for further studies in topology, analysis, complex analysis, and related fields.

# CC14: Numerical Methods

## (Credits: 04, Theory-04, Tutorial-00)

## Course Outcomes:

Upon successful completion of this course, students will be able to:

### Numerical Representation and Errors

- Understand how real numbers are represented in computers, including floating-point and fixed-point representations.
- Identify sources of errors in numerical computations, including rounding errors and error propagation.
- Analyze the stability and convergence of numerical algorithms.

### Approximation and Interpolation

- Explore classes of approximating functions, including polynomial approximations and the Weierstrass approximation theorem.
- Apply Lagrange and Newton's methods for interpolation, and estimate interpolation errors.
- Work with finite difference operators and perform forward, backward, and central interpolation using Newton's formulas.
- Apply Stirling's and Bessel's formulas for central interpolation, and estimate errors in different interpolation zones.
- Understand Hermite interpolation.

### Numerical Differentiation and Integration

- Perform numerical differentiation using methods based on interpolation and finite differences.
- Apply various numerical integration techniques, including Newton-Cotes formulas, trapezoidal rule, Simpson's rules, Weddle's rule, Boole's rule, midpoint rule, composite rules, and Gaussian quadrature.

### Numerical Solutions of Equations

- Apply various methods to find roots of transcendental and polynomial equations, including bisection, secant, regula-falsi, fixed-point iteration, and Newton-Raphson methods.
- Analyze the convergence properties of these methods, including conditions for convergence, order, and rate of convergence.
- Solve systems of nonlinear equations using Newton's method.

## Linear Systems and Eigenvalue Problems

- Solve systems of linear algebraic equations using direct methods (Gaussian elimination, Gauss-Jordan) and pivoting strategies.
- Solve systems using iterative methods (Gauss-Jacobi, Gauss-Seidel) and perform convergence analysis.
- Apply LU decomposition (Crout's method) for both solving systems and matrix inversion.
- Compute eigenvalues and eigenvectors using the power method.

## Ordinary Differential Equations

- Solve ordinary differential equations numerically using single-step difference equation methods, including Euler's method, modified Euler method, and Runge-Kutta methods of orders two and four.
- Analyze errors and convergence of these methods.

## Overall Course Outcomes:

- Develop a deep understanding of numerical methods and their applications in various areas of mathematics and computation.
- Apply numerical techniques to solve approximation, interpolation, differentiation, integration, root-finding, linear system, eigenvalue, and differential equation problems.
- Analyze errors and convergence of numerical algorithms, making informed choices for problem-solving.
- Gain proficiency in implementing numerical methods using computational tools.
- Prepare for further studies in numerical analysis, scientific computing, and related fields.

# CC14 Practical: Numerical Methods Lab

## (Credits: 02, Theory-00, Practical-02)

## Course Outcomes:

Here's a summary of the numerical methods practicals, highlighting key aspects and potential learning outcomes:

**Practical 1: Basic Programming Concepts**

- Reinforces fundamental programming constructs essential for numerical computations.
- Introduces variables, data types, operators, expressions, input/output, control flow, and arrays.

**Practical 2: Array Manipulation**

- Practices array handling and sorting algorithms, crucial for data organization and analysis.
- Underscores the importance of efficient data structures in numerical methods.

**Practicals 3-4: Root-Finding Algorithms**

- Explores various methods for solving transcendental and algebraic equations, emphasizing their convergence properties, error analysis, and suitability for different problem types.
- Develops problem-solving skills and understanding of iterative numerical techniques.

**Practicals 5-6: Linear System Solvers and Interpolation**

- Applies direct and iterative methods for solving linear systems, highlighting their computational efficiency and accuracy considerations.
- Implements interpolation techniques to approximate functions based on given data points.
- Introduces numerical differentiation and integration techniques for approximating derivatives and integrals.

**Practical 7: Eigenvalue Calculation**

- Demonstrates the power method for approximating dominant eigenvalues and eigenvectors, essential for matrix analysis and spectral applications.

**Practical 8: Data Fitting**

- Addresses polynomial curve fitting to model data and extract meaningful relationships.

**Practical 9: Ordinary Differential Equation Solvers**

- Introduces numerical techniques for approximating solutions of ODEs, essential for simulating dynamic systems across various scientific fields.
- Explores methods with varying accuracy and computational cost, emphasizing the importance of algorithm selection based on problem characteristics.

**Overall Learning Outcomes:**

- Develop coding proficiency in C/C++/FORTRAN 90 and apply it to numerical problem-solving.
- Gain hands-on experience with a wide range of numerical methods, understanding their theoretical underpinnings and practical implementation.
- Develop problem-solving skills and the ability to select appropriate numerical techniques for different mathematical problems.
- Appreciate the importance of error analysis and algorithm convergence for reliable numerical computations.
- Build a solid foundation for further studies in numerical analysis, scientific computing, and related fields.

# DSE-A1.1: Advanced Algebra

## (Credits: 06, Theory-05, Tutorial-01)

## Course Outcomes:

Upon successful completion of this course, students will be able to:

### Group Theory

- Understand group actions, stabilizers, and permutation representations.
- Apply group actions to prove theorems like Generalized Cayley's Theorem and the Index Theorem.
- Analyze group actions arising from conjugation, including class equations, conjugacy classes in Sn, and consequences.
- Explore p-groups, Sylow's theorems, Cauchy's theorem, and their implications.
- Prove the simplicity of An for $n \geq 5$ and apply non-simplicity tests to other groups.

### Ring Theory

- Define and work with principal ideal domains (PIDs) and principal ideal rings (PIRs).
- Distinguish between prime and irreducible elements in rings.
- Apply concepts of greatest common divisor (gcd) and least common multiple (lcm) in rings.
- Recognize Euclidean domains and their relationship to PIDs.
- Explore polynomial rings, the division algorithm, and consequences.
- Understand factorization domains, unique factorization domains (UFDs), and connections between PIDs, UFDs, factorization domains, and integral domains.
- Apply the Eisenstein criterion to establish unique factorization in Z[x].
- Construct ring embeddings and quotient fields.
- Define regular rings, examine their properties, and study ideals within regular rings.

### Overall Course Outcomes:

- Deepen knowledge of group theory, exploring group actions, conjugacy, p-groups, Sylow's theorems, simplicity, and non-simplicity tests.
- Develop a strong understanding of ring theory, covering PIDs, PIRs, Euclidean domains, polynomial rings, factorization domains, UFDs, quotient fields, and regular rings.
- Apply abstract algebraic concepts to solve problems and prove theorems in both group theory and ring theory.
- Strengthen mathematical problem-solving skills and analytical abilities in these areas.
- Prepare for further studies in algebra, abstract algebra, ring theory, and related fields.

# DSE-A1.2: Bio Mathematics

## (Credits: 06, Theory-05, Tutorial-01)

## Course Outcomes:

Upon successful completion of this course, students will be able to:

### Continuous Models

- Develop a working knowledge of mathematical biology and the modeling process.
- Apply continuous models like Malthus, logistic, Allee, and Gompertz to population growth dynamics.
- Analyze enzyme kinetics using Michaelis-Menten equations and understand Holling type models for predator-prey interactions.
- Model bacterial growth in a chemostat and simulate harvesting of natural populations.
- Investigate competition between populations and explore the dynamics of various epidemic models like SI, SIR, SIRS, and SIC.

### Advanced Continuous and Spatial Models

- Analyze models with feedback mechanisms like activator-inhibitor systems and study real-world examples like the Spruce Budworm outbreak.
- Learn numerical methods for solving differential equations and visualize model outputs graphically.
- Perform qualitative analysis of continuous models, including finding steady state solutions, determining stability through linearization, and applying the Routh-Hurwitz criterion to analyze multi-species communities.
- Employ phase plane methods to study qualitative solutions and explore bifurcations and limit cycles in biological contexts.
- Extend modeling to spatial dimensions by introducing diffusion in single and two-species models.
- Investigate diffusive instability conditions, analyze the spread of microorganisms and colonies, model blood flow in the circulatory system, and explore travelling wave solutions for gene propagation.

**Discrete Models**

- Gain an understanding of difference equations and their role in modeling biological systems.
- Analyze steady-state solutions and perform linear stability analysis for discrete models.
- Explore various types of discrete models, including linear, growth, decay, drug delivery, and predator-prey interactions.
- Analyze density-dependent growth models with harvesting and study host-parasitoid systems using the Nicholson-Bailey model.
- Solve discrete models numerically and represent solutions graphically.
- Delve into case studies highlighting applications of discrete models in optimal exploitation, genetics, stage structure, and age structure of populations.

**Graphical Demonstrations**

- Visualize and analyze various models using software tools, including:
  - Growth and decay models (exponential case)
  - Lake pollution model with constant/seasonal flow and pollution concentration
  - Effects of single and multiple cold pills
  - Limited population growth with and without harvesting
  - Predatory-prey models (basic Volterra, with density dependence, effect of DDT, two prey one predator)
  - Epidemic models of influenza (basic, contagious for life, disease with carriers)
  - Battle models (basic, jungle warfare, long-range weapons)

**Overall Course Benefits:**

- Gain a comprehensive understanding of mathematical modeling techniques in biology.
- Develop critical thinking skills to analyze and interpret biological phenomena through mathematical models.
- Enhance problem-solving abilities by applying mathematical concepts to complex biological systems.
- Equip yourself with valuable skills for research and analysis in diverse fields related to ecology, epidemiology, population dynamics, and more.

# DSE-B 1.2: Linear Programming & Game Theory

## (Credits: 06, Theory-05, Tutorials-01)

## Course Outcomes:

Upon successful completion of this course, students will be able to:

### Foundations of Linear Programming

- Define linear programming problems (LPPs) and recognize their applications in various domains.
- Formulate LPPs from real-world scenarios involving inequalities.
- Solve LPPs graphically for two-variable cases.
- Understand basic solutions and basic feasible solutions (BFS), and their role in solving LPPs.
- Represent LPPs in matrix form.
- Distinguish between degenerate and non-degenerate BFS.
- Explore geometric concepts of hyperplanes, convex sets, cones, extreme points, convex hulls, and convex polyhedrons.
- Apply supporting and separating hyperplanes to analyze LPPs.
- Establish connections between feasible solutions, extreme points, and BFS in the context of convexity.
- Apply the fundamental theorem of linear programming to locate optimal solutions.
- Address degeneracy and its resolution in LPPs.

### The Simplex Method

- Introduce slack and surplus variables to convert LPPs into standard form.
- Understand the theory underlying the simplex method, including feasibility and optimality conditions.
- Apply the simplex algorithm step-by-step to solve LPPs.
- Employ the two-phase method to handle LPPs with artificial variables.
- Resolve degeneracy issues that arise in the simplex method.

**Duality Theory**

- Formulate the dual problem for a given LPP.
- Explore relationships between the primal and dual problems, including their objective values and optimal solutions.
- Apply complementary slackness to derive insights into solutions.
- Utilize duality theory to interpret and enhance the simplex method.

**Applications and Game Theory**

- Solve transportation and assignment problems using specialized techniques, including the Hungarian method.
- Understand the structure of the traveling salesman problem and its challenges.
- Introduce game theory concepts, including rectangular games, pure and mixed strategies, saddle points, optimal strategies, and game values.
- Apply methods for solving rectangular games, such as dominance, algebraic, and graphical approaches.
- Establish connections between linear programming and game theory.

**Overall Course Outcomes:**

- Acquire a thorough understanding of linear programming concepts, theory, and solution techniques.
- Develop proficiency in formulating and solving LPPs using graphical and simplex methods.
- Grasp duality theory and its applications in linear programming.
- Solve transportation, assignment, and game theory problems.
- Sharpen analytical and problem-solving skills in optimization and decision-making contexts.
- Prepare for further studies in operations research, mathematical optimization, and related fields.

# DSE-A2.2: Mathematical Modelling

## (Credits: 06, Theory-05, Tutorial-01)

## Course Outcomes:

Upon successful completion of this course, students will be able to:

### Special Functions and Laplace Transforms

- Develop skills in solving Bessel's and Legendre's equations using power series methods.
- Master the Laplace transform technique and its inverse, applying them to solve initial value problems involving second-order differential equations.

### Simulation Modeling and Optimization

- Understand the principles of Monte Carlo simulation and its use in modeling deterministic behavior, including estimation of areas and volumes.
- Implement random number generators, including middle square and linear congruence methods.
- Construct queuing models to analyze systems like harbor traffic and morning rush hour.
- Gain an overview of optimization modeling, focusing on linear programming.
- Apply geometric and algebraic solution techniques to linear programming problems.
- Master the simplex method for solving linear programs and perform sensitivity analysis.

### Graphical Demonstrations (Using Free Software)

- Reinforce theoretical concepts through hands-on programming and visualization exercises:
- Plot Legendre polynomials and verify root properties.
- Automate series solution computations for ordinary points.
- Generate plots of Bessel functions.
- Implement the Frobenius Series Method.
- Generate random numbers for geometric simulations.
- Program single or multiple server queuing models.
- Develop a simplex method algorithm for 2/3 variable problems.

**Overall Course Outcomes:**

- Develop proficiency in solving special differential equations using power series methods.
- Apply Laplace transforms to solve initial value problems.
- Gain expertise in Monte Carlo simulation techniques for modeling and estimation.
- Construct and analyze queuing models for various systems.
- Solve linear programming problems using geometric, algebraic, and simplex methods.
- Conduct sensitivity analysis to understand model behavior under changing conditions.
- Enhance programming skills in R, SageMath, Python, or similar free software.

# DSE-B2.1: Point Set Topology

## (Credits: 06, Theory-05, Tutorial-01)

## Course Outcomes:

Upon successful completion of this course, students will be able to:

### Foundations of Topology

- Define topological spaces and their fundamental concepts, including bases, subbases, neighborhoods, interior points, limit points, closures, boundaries, open and closed sets, and dense subsets.
- Construct subspace topologies and finite product topologies.
- Characterize continuous functions, open maps, closed maps, and homeomorphisms.
- Identify topological invariants and understand their importance.
- Explore metric topologies, isometries, and metric invariants.

### Separation Axioms and Convergence

- Introduce the separation axioms T1 and T2, and their roles in distinguishing topological spaces.
- Define convergence and cluster points of sequences in topological spaces.
- Relate these concepts to first countability and T2 spaces.
- Apply Heine's continuity criterion to analyze functions on compact spaces.

### Connectedness and Compactness

- Define connected spaces and identify connected sets in R.
- Study components and their properties.
- Explore compact spaces, their relationship with T2 separation, and compact sets in R.
- Prove the Heine-Borel Theorem for Rn.
- Analyze real-valued continuous functions on connected and compact spaces.
- Examine compactness in metric spaces and establish the equivalence of sequential compactness and the Bolzano-Weierstrass property.

**Overall Course Outcomes:**

- Develop a solid understanding of the fundamental concepts of topology.
- Construct and analyze various topological spaces.
- Apply topological concepts to continuous functions, homeomorphisms, and invariants.
- Differentiate topological spaces using separation axioms.
- Analyze convergence and continuity in topological spaces.
- Identify and characterize connected and compact spaces.
- Apply these concepts to metric spaces and real-valued continuous functions

# DSE-B2.3: Advanced Mechanics

## (Credits: 06, Theory-05, Tutorial-01)

## Course Outcomes:

Upon successful completion of this course, students will be able to:

### Lagrangian Mechanics

- Apply concepts of degrees of freedom and constraint reactions to analyze mechanical systems.
- Utilize D'Alembert's principle to derive equations of motion.
- Formulate Lagrangian equations of the first and second kind for generalized coordinates and forces.
- Identify and handle cyclic coordinates and velocity-dependent potentials.
- Apply the principle of energy and utilize Rayleigh's dissipation function for energy analysis.

### Hamiltonian Mechanics and Conservation Laws

- Understand the Action Integral and connect it to Hamilton's principle for deriving Lagrange's equations.
- Extend Hamilton's principle to non-holonomic systems.
- Relate symmetries of the system to conservation laws using Noether's theorem.
- Define canonically conjugate coordinates and momenta through Legendre transformation.
- Formulate the Routhian approach and express the Hamiltonian of a system.

### Variational Principles and Applications

- Derive Hamilton's equations from the variational principle.
- Understand the Poincare-Cartan integral invariant and its role in classical mechanics.
- Apply the principle of stationary action to analyze physical phenomena like Fermat's principle in optics.

### Canonical Transformations and Advanced Techniques

- Perform canonical transformations using generating functions and analyze their implications.
- Calculate Poisson brackets for various dynamical variables and apply them to the equations of motion.
- Introduce action-angle variables and solve Hamilton-Jacobi's equation to find Hamilton's principal function and characteristic function.
- Apply Liouville's theorem to analyze phase space dynamics and conservation of volume.

**Overall Course Outcomes:**

- A comprehensive understanding of Lagrangian and Hamiltonian mechanics as powerful tools for analyzing classical systems.
- The ability to formulate and solve the equations of motion for diverse mechanical systems.
- An appreciation for the connection between symmetries and conservation laws in physics.
- Solid grounding in advanced techniques like canonical transformations and Hamilton-Jacobi theory.
- Preparation for further studies in theoretical mechanics, classical field theory, and related areas.

# SEC-A1.1: C Programming Language

## (Credits: 02, Theory-02, Project-00)

## Course Outcomes:

Upon successful completion of this course, students will be able to:

**Understand Fundamentals of Computer Systems:**

- Explain the historical development and theoretical concepts of computers.
- Identify the key components of a computer architecture.
- Compare and contrast different types of programming languages, including machine language, high-level languages, and object-oriented languages.
- Grasp the importance and features of the C programming language.

**Master C Programming Syntax and Constructs:**

- Define and utilize various data types, constants, and variables in C programs.
- Formulate and evaluate expressions using arithmetic, relational, and logical operators.
- Implement control flow statements like if-else, switch, and loops (while, do-while, for) to control program execution.
- Work with arrays in one, two, and multidimensional forms, understanding their declaration and initialization.

**Develop Function Building Skills:**

- Define, call, and utilize user-defined functions with different return types and variable scopes.
- Pass arrays as arguments to functions and leverage function nesting effectively.
- Write recursive functions and analyze their behavior.

**Utilize Standard Library Functions:**

- Employ common library functions from headers like stdio.h, math.h, string.h, stdlib.h, and time.h to enhance their programs.
- Apply Programming Concepts through Practical Exercises.
- Implement hands-on examples and solve problems to solidify your understanding of C programming concepts.

**Overall Course Outcomes:**

- A solid foundation in C programming language, enabling you to write efficient and functional code.
- The ability to analyze and solve computational problems through programming.
- Basic understanding of computer systems and different programming paradigms.
- Valuable skills for further computer science and programming courses.

# SEC-A1.2: Object Oriented Programming in C++

## (Credits: 02, Theory-02, Project-00)

## Course Outcomes:

Upon successful completion of this course, students will be able to:

**Unit 1:**

- Comprehend the fundamental concepts of programming paradigms, with a focus on object-oriented programming (OOP).
- Identify the key characteristics of OOP languages and their advantages.
- Trace the historical evolution of C++ and its relationship to C.
- Construct basic C++ programs, employing correct syntax, operators, variables, enumerations, arrays, and pointers.

**Unit 2:**

- Demonstrate proficiency in defining and working with objects and classes, the cornerstones of OOP.
- Employ constructors and destructors to manage object lifecycles effectively.
- Utilize friend functions and inline functions to enhance code organization and performance.
- Apply the principles of encapsulation, data abstraction, inheritance, polymorphism, and dynamic binding to create robust and flexible code structures.
- Overload operators and methods to extend functionality and achieve cleaner code.

**Unit 3:**

- Master template classes to create generic code adaptable to various data types.
- Grasp the concepts of copy constructors, subscript operators, and function call operators to manage objects effectively.
- Organize code using namespaces to prevent naming conflicts and improve code clarity.
- Implement exception handling techniques to manage errors gracefully and ensure program stability.
- Apply learned concepts to solve practical programming problems through hands-on exercises, including those listed in the syllabus.

## Overall Course Outcomes:

- Gain a solid foundation in C++ programming, enabling them to create well-structured, object-oriented applications.
- Develop a deep understanding of OOP principles and their practical implementation.
- Apply advanced C++ features, such as templates, operator overloading, and exception handling, to solve complex programming tasks.
- Build problem-solving and analytical skills through hands-on programming experience.
- Prepare for further studies in computer science and related fields that require knowledge of C++.

# SEC-B1: Scientific computing with SageMath & R

## (Credits: 02, Theory-02, Project-01)

## Course Outcomes:

Upon successful completion of this course, students will be able to:

**Software Familiarity:**

- Install and navigate SageMath and R effectively.
- Utilize SageMath and R as powerful calculators for numerical and symbolic computations.
- Perform mathematical operations involving square roots, trigonometric functions, logarithms, exponentiations, and more.

**Visualization:**

- Generate graphical representations of various functions within specified intervals.
- Plot polynomial, trigonometric, and polar curves, handling asymptotes and multiple graphs in a single plot.
- Create combined plots of functions and their derivatives.

**Calculus:**

- Employ SageMath and R commands for differentiation, higher-order derivatives, integration, and definite integrals.
- Visualize functions and their derivatives simultaneously.

**Programming Fundamentals:**

- Write basic programs in SageMath and R using relational and logical operators, conditional statements, and loops.
- Calculate statistical measures like average, mean, median, mode, factorial, and gcd/lcm without relying on inbuilt functions.
- Implement algorithms for prime number checking, finding primes within intervals, and determining sequence convergence.

**Mathematical Operations:**

- Utilize inbuilt functions for matrix operations, including determinants, inverses, linear system solving, polynomial root finding, and differential equation solving.

**Hands-on Experience:**

- Apply learned concepts to solve practical mathematical problems through guided hands-on examples.

**Overall Course Outcomes:**

- Gain a solid foundation in using SageMath and R for mathematical computations, visualization, and programming.
- Develop problem-solving skills within a mathematical context through hands-on practice.
- Be prepared for further studies or research involving mathematical computations and data analysis using these software tools.