Central University of Punjab, Bathinda

M.Sc. Mathematics

Batch: 2025-2026

Department of Mathematics and Statistics
School of Basic Science

M.Sc. (Mathematics) Programme

Graduate Attributes:

Students will be able to develop a broad understanding of recent mathematical theories, tools and techniques. Students will apply different mathematical techniques in various fields and will independently plan and carry out research in pure and applied mathematics. They will compete at regional/national/international level for research/jobs in the area of mathematics.

M.Sc. Mathematics (2 years):

- Two semesters of course work and two semesters of research work.

The Programme will have the following credit distribution:

Curriculum Components	Two Year M.Sc. Mathematics Minimum Credits			
	Course Level	Course Work	Research Thesis	Total Credits
1st Year Sem 1	400	20	–	44
1st Year Sem 2	500	24	–	
2nd Year Sem 3	–	–	20	40
2nd Year Sem 4	–	–	20	

M.Sc. Mathematics (Semester-I)

Course Code	Course Title	Course Type	Credit Hours			Credits
			L	T	P	
MMAT.516	Modern Algebra	DSC	3	0	0	3
MMAT.517	Topology	DSC	3	0	0	3
MMAT. 518	Differential Geometry	DSC	3	0	0	3
MMAT.519	Differential Equations	DSC	3	0	0	3
MMAT.520	Real Analysis	DSC	3	0	0	3
Skill Enhancement (Practicals/Skill base Courses)						
MMAT.401	Introduction of Mathematica and MATLAB	SEC	0	0	2	1
MMAT.402	Python for Mathematical Computing	SEC	0	0	2	1
MMAT.403	Linear Algebra	SEC	3	0	0	3
	Remedial Classes		0	2*	0	0
Total Credits			**18**	**2**	**4**	**20**

DSC – Discipline Specific Core, DEC – Discipline Elective Course, SEC–Skill Enhancement Course

Semester-II

Course Code	Course Title	Course Type	L	T	P	Cr
MMAT.521	Differentiable Manifolds	DSC	3	0	0	3
MMAT.522	Measure theory	DSC	3	0	0	3
MMAT.523	Functional Analysis	DSC	3	0	0	3
Discipline Elective Course (any one of the following):						
MMAT.524	Tensor Algebra	DEC	3	0	0	3
MMAT.525	Bio-Mathematics	DEC	3	0	0	3
MMAT.526	Dynamical Systems	DEC	3	0	0	3
Skill Enhancement (Practicals/Skill base Courses)						
MMAT.404	Numerical Analysis	SEC	3	0	0	3
MMAT.405	Basics of Latex (Practical)	SEC	0	0	2	1
MMAT.406	Symbolic Computations and Plotting	SEC	0	0	2	1
Ability Enhancement Course						
MMAT.407	Complex Analysis	AEC	3	0	0	3
***Interdisciplinary Course** (choose a course from the Interdisciplinary courses offered in the University)*						
MMAT.506 to MMAT.508	Interdisciplinary Course	IDC	2	0	0	2
***Value-added Course** (choose a Course from the Value Added Courses offered in the University)*						
MMAT.511 to MMAT.513	Value-added Course	VAC	2	0	0	2
Total Credits			**22**	**0**	**4**	**24**

Interdisciplinary courses offered by Department of Mathematics and Statistics (For PG students of other Departments)

Course Code	Course Name	Course Type	L	T	P	C
MMAT.506	Basic Mathematics	IDC	2	0	0	2
MMAT.507	Vector Analysis					
MMAT.508	Numerical Methods					

Value added courses offered by Department of Mathematics and Statistics (For PG students of other Departments)

Course Code	Course Name	Course Type	L	T	P	C
MMAT.511	Linear Programming	VAC	2	0	0	2
MMAT.512	Mathematical Methods					
MMAT.513	Vedic Mathematics and Data Science					

*MOOCs may be taken up 40% of the total credits (excluding dissertation credits). MOOC may be taken in lieu of any course but content of that course should match a minimum 70%. Mapping is to be done by the respective department and students may be informed accordingly.

M.Sc. Mathematics (Semester III)

Course Code	Course Title	Course Type	Credit Hours			Course Credits
			L	T	P	
MMAT.599-1	Dissertation Part- I	Skill Based	0	0	40	20

Students will have an option to carry out dissertation work in industry, national institutes or Universities in the top 100 NIRF ranking.

Group dissertation may be opted, with a group consisting of a maximum of four students. These students may work using a single approach or multidisciplinary approach. Research projects can be taken up in collaboration with industry or in a group from within the discipline or across the discipline.

M.Sc. Mathematics (Semester IV)

Course Code	Course Title	Course Type	Credit Hours			Course Credits
			L	T	P	
MMAT.599-2	Dissertation Part- II	Skill Based	0	0	40	20

Students will have an option to carry out dissertation work in industry, national institutes or Universities in the top 100 NIRF ranking.

Group dissertation may be opted, with a group consisting of a maximum of four students. These students may work using a single approach or a multidisciplinary approach. Research projects can be taken up in collaboration with industry or in a group from within the discipline or across the discipline.

Total Credits for the course: 84

Examination pattern and evaluation Criteria for Core, Discipline Elective, Compulsory Foundation Courses:

Formative Evaluation: Internal assessment shall be 25 marks using any two or more of the given methods: tests, assignments, term paper, presentations etc. The Mid-semester test (MST) shall be

descriptive type of 25 marks including short answer and essay type except for some courses as given in the table below. Each answer shall carry a maximum weightage of five marks in MST. The teachers shall have the flexibility to decide on the number of questions and distribution of marks following above guidelines.

Summative Evaluation: The End semester examination (ESE) shall be 50 marks with upto 100% descriptive type and upto 30% objective type shall be conducted at the end of the semester. The objective

type shall include a few words (very short) answers, fill-in the blanks, MCQs', and matching. Each answer shall carry weightage of upto two marks depending on the level of difficulty. The descriptive type shall include short answer and essay type questions. Each answer shall carry a maximum weightage of ten marks in ESE. The teachers shall have the flexibility to decide on the number of questions and distribution of marks following above guidelines. Questions for exams and tests shall be designed to assess course learning outcomes along with focus on knowledge, understanding, application, analysis, synthesis, and evaluation.

Evaluation Criteria for IDC, VAC and entrepreneurship, innovation and skill development courses

The evaluation for IDC, VAC and entrepreneurship, innovation and skill development courses (<2 credits) shall include MST (50 marks) and ESE (50 marks). The pattern of examination for both MST and ESE shall be the same as given in the table (Annexure II).

Evaluation of dissertation proposal and presentation in the third semester shall include 50% weightage by supervisor and 50% by HoD and senior-most faculty of the department. The evaluation of dissertation in the fourth semester shall include 50 marks for continuous evaluation by the supervisor for regularity in work, mid-term evaluation, report of dissertation, presentation, and final viva-voce; 50 marks (50% weightage) by an external expert shall be based on report of dissertation (25 marks), presentation (10 marks), novelty/originality (5 marks) and final viva-voce (10 marks). The external expert may attend final viva-voce through offline or online mode.

Dissertation:

A. Third semester (Based on Dissertation proposal and presentation)

a) Supervisor [50% weightage]
b) HoD and Senior most faculty [50% weightage]

B. Fourth semester (Based on Dissertation)

a) Continuous assessment, report, presentations, viva voce: Supervisor [50% weightage]
b) Report of dissertation (25 marks), presentation (10 marks), novelty/originality (5 marks) and final viva-voce (10 marks): External expert [Total 50% weightage] .

Evaluation Criteria for Practical classes

A. Practical file: [15 Marks]
B. Practical Exam: [70 Marks]
C. Viva-Voce Examination: [15 Marks]

M. Sc. Mathematics (Semester-I)

Course title: Modern Algebra
Course Code: MMAT.516
Course Type: Core
Total Hours: 45

L	T	P	Credits
3	0	0	3

Learning Outcomes: Upon the completion of the course, the student will be

CLO1: Able to understand the group homeomorphisms and properties of cyclic groups
CLO2: Able to understand the ring homeomorphisms and properties of ideals
CLO3: Able to apply Eisenstein's irreducibility criteria.
CLO4: Able to understand vector spaces algebraically as free modules and appreciate the differences between modules defined over different rings.

Units/Hours	Contents	Mapping with CLO
I 12 Hours	Groups, subgroups, normal subgroups, quotient groups, homomorphisms, cyclic groups, permutation groups, Cayley's theorem, class equations,	CLO1
II 11 Hours	Rings: Introduction to rings, examples, ideals, ring homomorphisms, quotients with examples. Isomorphism theorems, Prime and maximal ideals, basic properties of ideals, local rings, Radical ideals, Nil radical, Jacobson radical	CLO2
III 12 Hours	Integral domains, field of fractions, Euclidean Domains, Principal Ideal Domains, Unique factorization domains, Gauss lemma, Eisenstein's irreducibility criterion.	CLO3
IV 10 Hours	Modules: Introduction to Modules over arbitrary rings, examples, Free modules, submodules, quotient modules, module homomorphisms, direct sums, direct products.	CLO4

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. M. Artin, Algebra, Second edition, Pearson Education India, 2010
2. D. S. Dummit, and M. F. Richard, *Abstract algebra*. Vol. 3. Hoboken: Wiley, 2004.
4. C. Musili, Introduction to Rings & Modules, Narosa Publishing House, 1997..
5. I. N. Herstein, *Topics in algebra*, John Wiley & Sons, 1991.
6. B. Hartley and T. O. Hauvkes, Rings, Modules and Linear Algebra, Chapmann and Hall Ltd., 1970.

Course Title: Topology
Course Code: MMAT.517
Course type: Core
Total Hours: 45

L	T	P	Credits
3	0	0	3

Learning outcomes:
The students will be able to
CLO1: Describe Topological spaces with examples and related concepts in detail.
CLO2: Explain continuous functions in topology and its characterizations.
CLO3: Understand various topological properties with examples.
CLO4: Explain the concept of Compact spaces and its consequences.
CLO5: Discuss various separation axioms with their usage to prove many important results in topology.

Units/Hours	Contents	Mapping with CLO
I 12 Hours	Topological spaces: Definitions and Examples, Basis and Subbasis for a Topology, limit points, closure, interior; Continuous functions, Homeomorphisms; Subspace Topology, Metric Topology, Product & Box Topology, Order Topology; Quotient spaces. **Activity:** Students will work with some new topological spaces and continuous functions defined on them. They will try to find spaces which are Homeomorphic or not.	CLO1 CL02
II 12 Hours	Connectedness: Connected spaces, Connected subspaces of the real line, Components and path components, Local connectedness. **Activity:** Students will work on how various topological surfaces are constructed. They will also work on various examples of connected and disconnected spaces and its applications to detect when two topological spaces are not homeomorphic.	CLO3
III 11 Hours	Compactness: Compact spaces, Sequentially compact spaces, Heine-Borel theorem, Compact subspaces of the real line, Limit point compactness, Local–compactness and one point compactification. **Activity:** Students will explore other important topological properties with examples and applications which will again help to determine non-homeomorphic topological spaces.	CLO4
IV 10 Hours	**Countability Axioms:** First countable spaces, Second countable spaces, Separable spaces, Lindeloff spaces. Separation Axioms: Hausdorff, Regular and Normal spaces; Urysohn's lemma; Uryohn'sMetrization theorem; Tietze extension theorem. (Statements only). **Activity:** Students will try to find applications of different separation axioms along with its importance to find new results in topology.	CLO5

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. M. A. Armstrong, *Basic Topology*, Paperback Edition, Springer, 2004.
2. James Dugundji, *Topology,* Universal Book Stall, New Delhi, 1990.
3. J. L. Kelley, *General Topology*, GTM, First Edition, Springer, 1975.
4. S. Kumaresan, *Topology of Metric Spaces,* second edition*,* Narosa Publishing House New Delhi, 2015.
5. J. R. Munkres, *Topology,* Second Edition, Pearson India Education services Pvt. Ltd., 2015.
6. G. F. Simmons, *Introduction to Topology & Modern Analysis*, McGraw Hill, Auckland, 1963.

Course Title: Differential Geometry
Course Code: MMAT.518
Course type: Core
Total Hours: 45

L	T	P	Credits
3	0	0	3

Learning outcomes: The students will be able to

CLO1: Learn the basic concepts of plane and space curves.
CLO2: Understand the theory of surfaces in R^3.
CLO3: Define the first and second fundamental forms.
CLO4: Illustrate various properties of curvature.
CLO5: Explain the theory of geodesics and relation between geometry and topology.

Units/Hours	Contents	Mapping with CLO
I 12 Hours	Parameterized curves, Tangent vector, Arc length, Reparametrization, Closed curves, Smooth and Regular curves, Curvature and torsion of smooth curves, Frenet-Serret formulae, Simple closed curves, Hopf's Umlaufsatz Theorem, Isoperimetric inequality, Wirtinger's Inequality, Four vertex theorem. **Activity:** To find curvature and torsion of some important plane and space curves and study global properties of curves.	CLO1
II 11 Hours	Definition and examples of surfaces, Smooth surfaces, Smooth maps, Tangents and derivatives, Normal and orientability. Examples of surfaces: Level surfaces, generalized cylinder and generalized cone, Ruled surfaces, Surface of revolution, Compact surfaces. First fundamental form, Isometries of surfaces, Conformal mapping of surfaces, Equiareal maps and theorem of Archimedes. **Activity:** To find the first fundamental form and surface area of some important surfaces.	CLO2
III 11 Hours	Second fundamental form, Gauss and Weingarten maps, Normal and geodesic curvatures, Meusnier's theorem, Parallel transport and covariant derivative, Gaussian and mean curvatures, Principal curvatures, Euler's theorem, Surfaces of constant Gaussian curvature, Flat surfaces, Surfaces of constant mean curvature, Gaussian curvature of compact surfaces. **Activity:** To find a second fundamental form, principal curvatures and Gaussian curvature of some important surfaces.	CLO3

IV 11 Hours	Definition and examples of geodesics, Geodesic equations, Geodesics on a surfaces of revolution, Clairaut's theorem, Geodesics as shortest paths, Geodesic coordinates, Gauss and Codazzi-Mainardi equations, Gauss' Remarkable Theorem, Surfaces of constant Gaussian curvature. Gauss-Bonnet Theorem (Statement only). **Activity:** To find geodesics, geodesic equations and compact surfaces of constant Gaussian curvature.	CLO4 CLO5

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. C. Baer, *Elementary Differential Geometry*, Cambridge University Press, 2001.
2. M. P. Do Carmo, *Differential Geometry of Curves and Surfaces*, Revised and Updated Second Edition, Prentice-Hall Inc., Englewood Cliffs, New Jersey, 2016.
3. A. Gray, E. Abbena, and S. Salamon, *Modern Differential Geometry of Curves and Surfaces with Mathematica*, Third edition, CRC Press, 2006.
4. R. S. Millman & G. D. Parkar, *Elements of Differential Geometry*, Englewood Cliffs, N.J. : Prentice Hall, 1977.
5. B. O' Neill, *Elementary Differential Geometry*, Revised Second Edition, Academic Press, 2006.
6. A. Pressley, *Elementary Differential Geometry*, Second Edition, Undergraduate Mathematics Series, Springer-Verlag London Ltd., 2010.

Course Title: Differential Equations
Course Code: MMAT.519
Course type: Core
Total Hours: 45

L	T	P	Credits
3	0	0	3

Learning outcomes:

The students will be able to

CLO1. Review the basic concepts of Cauchy Problems for First Order Hyperbolic Equations.

CLO2. Explain the methods for solving second order Partial Differential Equations with variable coefficients.

CLO3. Understand how the solutions of problems are dependent on Initial and Boundary values

CLO4. Apply the method of separation of variables for solving Heat, Wave and Laplace equations.

Units/Hours	Contents	Mapping with CLO
I 10 Hours	Linear Second Order Equations - Initial value problem, Existence and Uniqueness by Picard's Theorem, Wronskian, General theory of homogenous and non-homogeneous linear **Activity:** Students will explore the existence and uniqueness of solutions of Initial Value Problems.	CLO1
II 11 Hours	Variation of parameters. Boundary value problems – Sturm - Liouvile system, eigen values and eigen functions, simple properties, expansion in eigen functions, Green's function method. **Activity:** Students will explore the formation of second order partial differential equations representing some real phenomena.	CLO2
III 12 Hours	Power series solutions - Solution near ordinary and regular singular point. Convergence of the formal power series. Partial differential equations - Lagrange and Charpit methods for solving first order PDEs, **Activity:** Students will explore how the solutions of Sturm - Liouvile system	CLO3
IV 12 Hours	Cauchy problems and characteristics, Classification of Second order PDE's, reduction to canonical forms, Method of separation of variables for Laplace, Heat and Wave equations. **Activity:** Students will derive the Laplace, heat and wave equations.	CLO4

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. Simmons, G.F.**,** *Differential Equations with Applications and Historical Notes*, McGraw-Hill, New York, 1991.
2. Sneddon, I.N., *Elements of Partial Differential Equations*, Dover Publications, New York, 2006.
3. Amarnath, T.**,** *An Elementary Course in Partial Differential Equations*, Narosa Publishing House, New Delhi, 2005.
4. Boyce, W.E. and DiPrima, R.C**.**, *Elementary Differential Equations and Boundary Value Problems*, Wiley, New York, 2008.

Course Title: Real Analysis
Course Code: MMAT.520
Course type: Skill based
Total Hours: 45

L	T	P	Credits
3	0	0	3

Learning outcomes:

The students will be able to

CLO1: Apply the knowledge of set theory and metric spaces with properties.

CLO2: Illustrate various properties of compact sets and connected sets.

CLO3: Explain concepts of convergent sequences and continuity in metric spaces.

CLO4: Apply the knowledge of Riemann Stieltjes Integrals.

CLO5: Discuss the problem of interchange of limit processes for sequences of functions and pointwise/Uniform convergence of sequence of functions.

Units/Hours	Contents	Mapping with CLO
I 12 Hours	**Metric spaces:** Definition and examples, Open and closed sets, Compact sets, Elementary properties of compact sets, k- cells, Compactness of k-cells, Compact subsets of Euclidean space $\Re^k$, Bolzano Weierstrass theorem, Heine Borel theorem, Perfect sets, Cantor set, Separated sets, Connected sets in a metric space, Connected subsets of real line. **Activity:** Students will solve some problems which will be based on concepts of compact sets and connected sets	CLO1 CL02
II 11 Hours	**Sequences in Metric spaces:** Convergent sequences, Subsequences, Cauchy sequences, Complete metric space with examples, Cantor's intersection theorem (Statement only), Category of a set and Baire's category theorem. Banach contraction principle. **Activity:** Students will solve some problems which will be based on application of sequences, category theorem and Banach contraction theorem.	CLO3
III 12 Hours	**Continuity:** Limits of functions (in Metric spaces), Continuous functions, Continuity and compactness, Continuity and connectedness, Discontinuities, Uniform continuity. **Riemann Stieltje's Integral:** Definition and existence of Riemann Stieltje's integral, Properties of integral. Integration and Differentiation. Fundamental Theorem of Calculus, 1st and 2nd Mean Value Theorems of Riemann Stieltje's integral. **Activity:** Students will do examples/exercises related to continuity and its characterizations. Students will explore how Riemann Stieltje's integral is a generalization of Riemann integral.	CLO4

IV 10 Hours	**Sequences and series of functions:** Problem of interchange of limit processes for sequences of functions, Uniform convergence, Uniform convergence and continuity, Uniform convergence and integration, Uniform convergence and differentiation. **Activity:** Students will explore how uniform convergence is related to integration and differentiation.	CLO5

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. T. M. Apostol, *Mathematical Analysis*, 2nd Edition, Addition –Wesley, USA, 2002.
2. A. Kumar and S. Kumaresan, *A Basic Course in Real Analysis*, Narosa, Publishing House, New Delhi, 2014.
3. W. Rudin, *Principles of Mathematical Analysis,* 3rd Edition, McGraw Hill, Kogakusha, International student Edition, 1976.
4. E. C. Titchmarsh, *The Theory of functions,* Oxford University Press, Oxford, 2002.
5. S. P. S. Kainth, A Comprehensive Textbook on Metric Spaces, Springer Verlag, Singapore, 2023.

Course Title: Introduction of Mathematica and MATLAB
Course Code: MMAT.401
Course Type: Skill based
Total Hours: 45

L	T	P	Credits
0	0	2	1

Total Hours: 30

Laboratory work:

Students will use software MATHEMATICA/MATLAB for performing following activities

1. Introduction to Interface & Basic Operations: Perform arithmetic operations (+, -, *, /, ^). Define variables and evaluate expressions

2. Plotting of plane curves. Computing the length and curvature of plane curves.

3. Matrices & Linear Algebra: Define matrices, compute determinants, inverses, eigenvalues.

4. Solve ODEs. Plot solution Curves.

5. Plot 3D surfaces. Contour plots and parametric curves.

6. Plot a **helix** (rcos t,rsin t,t) and compute its arc length.

7. Phase portrait of dynamical systems. Example $x^{\cdot}=y$, $y^{\cdot}=-x$.

8. Simulate **Lotka-Volterra model**: $x^{\cdot}=\alpha x-\beta xy$, $y^{\cdot}=\delta xy-\gamma y$.

9. **Heat Equation**: Solve $ut = kuxx$ with boundary conditions. **MATLAB**: Use pdepe; **Mathematica**: NDSolve. Plot solution evolution.

10. Compute curvature, torsion, and Frenet-Serret frame. For **r**(*t*)=(*t*,*t*^2,*t*^3), find: Unit tangent **T**(*t*). Curvature κ(t) **Mathematica**: Use FrenetSerretSystem.

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. C. Baer, *Elementary Differential Geometry*, Cambridge University Press, 2001.
2. Strogatz, S. H. (2018). *Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry, and Engineering* (2nd ed.). CRC Press.
3. A. Gray, E. Abbena, and S. Salamon, *Modern Differential Geometry of Curves and Surfaces with Mathematica*, Third edition, CRC Press, 2006.
4. Attaway, S. (2019). *MATLAB: A Practical Introduction to Programming and Problem Solving* (5th ed.). Academic Press.

Course Title: Python for Mathematical Computing
Course Code: MMAT.402
Course type: Skill Based

Total Hours: 30

L	T	P	Credits
0	0	2	1

Learning Outcome.
The students will be able to

- Explain various mathematical operators
- Illustrate mathematical function in **Python**
- Discuss methods to handle dataset in **Python**

Laboratory Work. Program related to Python programming.

1. A brief introduction about Python and installation of anaconda.
2. Numerical computations including square root, trigonometric functions using math and cmath module.
3. Dealing with different data types such as list, tuple and dictionary.
4. If statements, for loop and While loops and simple programmes using these.
5. User-defined functions and modules.
6. Various uses of lists, tuples and dictionaries.
7. Use of Matplotlib to plot graphs in various formats.
8. Classes in Python.
9. Use of Numpy and Scipy for solving problems in linear algebra and calculus, differential equations.
10. Data handling using Pandas

Transaction mode: Lecture/Co Operative learning/ Practical/ Group discussion/Team teaching /Tutorial/Problem solving/Self-learning.

Suggested Reading

1. Kenneth A, Fundamentals of Python First programs 2nd edition - Lambert, Cengage, Learning India.
2. Amit Saha, Doing Math with Python -, No starch Press,
3. E. Balgurusamy, Problem solving and Python programming- Tata McGraw Hill.

Course Title: Linear Algebra
Course Code: MMAT.403
Course type: Skill based
Total Hours: 45

L	T	P	Credits
3	0	0	3

Learning outcomes:

The students will be able to

CLO1: Review the basic notions in linear algebra that are often used in mathematics and other sciences

CLO2: Define Vector spaces, Subspaces and related results.

CLO3: Define Linear transformations and characteristic polynomials with examples.

CLO4: Illustrate various properties of canonical forms.

CLO5: Study of inner product spaces.

CLO6: Explain concepts of the Gram-Schmidt orthogonalization process and its application in construction of orthonormal basis.

Units/Hours	Contents	Mapping with CLO
I **11 Hours**	**Linear Transformations:** Linear transformations, Algebra of linear transformations, Isomorphism, **Matrix representation:** Matrix representation of a linear transformation. Change of basis, Rank and nullity of a linear transformation. **Activity:** Students will try to find the applications of linear transformations and matrices	CLO1 CLO2
II **11 Hours**	Inner product spaces. Norms and distances, Orthonormal basis, Orthogonality, Schwarz inequality, The Gram-Schmidt orthogonalization process. Orthogonal and positive definite matrices. **Activity:** Students will try to find the applications of Gram-Schmidt orthogonalization process	CLO5 CLO6
III **12 Hours**	Annihilating Polynomials: Characteristic polynomial and minimal polynomial of a linear transformation, Characteristic values and Characteristic vectors of a linear transformation, Cayley Hamilton theorem. **Activity:** Students will try to find the applications of Cayley Hamilton theorem.	CLO3
IV **11 Hours**	Diagonalizing matrices, Diagonalizing real symmetric matrices, Characteristic polynomials and minimal polynomials of block matrices, Canonical forms: Jordan canonical forms, rational canonical forms. Quotient spaces, Bilinear forms, Symmetric and skew- Symmetric bilinear forms, Sylvester's theorem, quadratic forms, Hermitian forms. **Activity:** Students will try to find the applications of Characteristic	CLO4

	polynomials and minimal polynomials of block matrices.	

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. J. Gilbert and L. Gilbert, *Linear Algebra and Matrix Theory,* Cengage Learning, 2004.
2. K. Hoffman and R. Kunze: *Linear Algebra*, Pearson Education (Asia) Pvt. Ltd/ Prentice Hall of India, 2018.
3. V. Bist and V. Sahai, *Linear Algebra,* Narosa, Delhi, 2002.
4. S Lang, Linear Algebra, Undergraduate texts in mathematics, Springer, 1989.

Semester-II

Course Title: Differentiable Manifolds
Course Code: MMAT.521
Course type: Core
Total Hours: 45

L	T	P	Credits
3	0	0	3

Learning outcomes: After completing this course **t**he students will be able to

CLO1: understand and explain the basic concept of smooth manifolds and smooth functions.

CLO2: know the basic concepts of Submersions, Immersions and embeddings, Smooth covering maps and Bump functions.

CLO3: explain the concepts of Submanifolds, Vector fields and Lie brackets.

CLO4: grasp the concepts of Lie groups, Lie algebra, Group actions and Equivariant maps.

Units/Hours	Contents	Mapping with CLO
I 12 Hours	Topological manifolds, Charts, Atlases, Definition and examples of Smooth manifolds, Manifolds with boundary, Smooth functions on manifolds, Smooth maps between manifolds, Diffeomorphisms, Partition of Unity and Bump functions. **Activity:** Exercises on charts, atlases and smooth maps.	CLO1
II 11 Hours	Tangent vectors and tangent space, Differential of a smooth map, Tangent bundle, Velocity vector of curves. Maps of constant rank: Submersions and Immersions. Embeddings, Critical and regular points, Smooth covering maps. **Activity:** Exercises on Rank of smooth map, submersion, immersion and embedding.	CLO2
I 11 Hours	Submanifolds: Embedded submanifolds, Immersed submanifolds, Restricting maps to Submanifolds, Tangent space to a submanifold. Vector fields, Vector fields and smooth maps, Lie bracket of vector fields, Integral curves and Flows of vector fields. **Activity:** Exercises on submanifolds, vector fields, Lie brackets and Integral curves.	CLO3
I 11 Hours	Definition and examples of Topological groups and Lie groups, Lie group homomorphism, Product of two Lie groups, Lie subgroups, Lie transformation groups, Left invariant vector fields of a Lie group, Lie Algebra of a Lie group. Group actions and Equivariant maps. **Activity:** Exercises on Lie groups and Group actions.	CLO4

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. W. M. Boothby, *An Introduction to Differentiable Manifolds and Riemannian Geometry*, 2nd edition, Academic Press, New York, 2003.
2. S. S. Chern, W. H. Chen and K. S. Lam, *Lectures on Differential Geometry*, World Scientific Publishing Co. Pvt. Ltd., 2000.
3. L. Conlon, *Differentiable Manifolds*, 2nd edition, Birkhauser Boston, Cambridge, MA, 2001.
4. N. J. Hicks,*Notes of Differential Geometry*, D. Van Nostrand Reinhold Company, New York, 1965.
5. S. Kumaresan, *A Course in Differential Geometry and Lie Groups (Texts and Readings in Mathematics),* Hindustan Book Agency, 2002.
6. J. M. Lee, *Introduction to Smooth Manifolds*, GTM, Vol. 218, Springer, New York, 2003.
7. W. Tu, *An Introduction to Manifolds*, Second edition, Springer, 2011.

Course Title: Measure Theory
Course Code: MMAT.522
Course type: Core
Total Hours: 45

L	T	P	Credits
3	0	0	3

Learning outcomes:
The students will be able to

CLO1. Explore the concept of algebras, σ –algebras and borel sets.
CLO2. Define Lebesgue outer measure and Lebesgue measure on R with their characterizations.
CLO3. Explain measurable functions and their properties.
CLO4. Discuss important theorems related to Lebesgue integral.
CLO5. Get in-depth understanding of Product Measure.

Units/Hours	Contents	Mapping with CLO
I 12 Hours	Semi-algebras, Algebras, Monotone class, σ -algebras, Measure and outer measures, Outline of extension of measures from algebras to the generated sigma-algebras: Measurable sets; Lebesgue Measure and its properties. Borel sets, Lebesgue outer measure and Lebesgue measure on R, Translation invariance of Lebesgue measure **Activity:** Students will find the outer measure of some sets and will apply these concepts in integration.	CLO1 CLO2
II 11 Hours	Continuity of measure and Borel-Cantelli Lemma, Existence of a non-measurable set, Measurability of Cantor set. Measurable functions on a measure space and their properties, Borel and Lebesgue measurable functions, Simple functions and their integrals, Littlewood's three principle and Egoroff's Theorem (statements only). **Activity:** Students will find some non-measurable sets and measurable functions. They will also try the proof of Littlewood's three principles and Egoroff's Theorem.	CLO3
III 11 Hours	Lebesgue integral on R and its properties. Bounded convergence theorem, Fatou's lemma, Lebesgue monotone convergence theorem, Lebesgue dominated convergence theorem, countable additivity and continuity of integration. **Activity:** Students will compare the Riemann integral and Lebesgue integral. They will also work on the counter examples where the above theorems fail to hold.	CLO4

IV 11 Hours	Functions of bounded variations: Jordan's theorem, Product Measure: an Introduction, Construction of Product Measures. **Activity:** Students will write some functions of bounded variations as the difference of two increasing functions.	CLO5

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. G.de Barra, *Measure Theory and Integration*, Ellis Horwood Limited, England, 2003.
2. G.B. Folland, *Real Analysis,* 2nd Edition, John Wiley, New York, 1999.
3. P. R. Halmos, *Measure Theory*, 14th Edition, Springer, New York, 1994.
4. B. Krishna and A. Lahiri, *Measure Theory*, Hindustan Book Agency, 2006.
5. I. K. Rana, *An Introduction to Measure and Integration,* 2nd Edition, Narosa Publishing House, New Delhi, 2005.
6. H. L. Royden, *Real Analysis*, Macmillan, New York, 1988.
7. T. Tao, *An introduction to measure theory*. Vol. 126. American Mathematical Soc., 2021.

Course Title: Functional Analysis
Course Code: MMAT.523
Course type: Core
Total Hours: 45

L	T	P	Credits
3	0	0	3

The students will be able to

CLO1. Describe the basic notion of normed linear spaces and Banach spaces with examples.
CLO2. Explain Bounded linear transformations and Dual spaces with related examples.
CLO3. Understand the concept of Reflexive spaces
CLO4. Discuss three main theorems on Banach spaces

Units/Hours	Contents	Mapping with CLO
I 10 Hours	**Fundamentals of Normed Linear Spaces:** Normed Spaces, with examples of Function spaces L^P([a,b]) ,C([a,b]) and C^1([a,b]), Sequence Spaces l^p, c , c_0, c_{00} Banach spaces and examples, finite dimensional normed spaces and subspaces. **Activity:** Students will find examples of Banach spaces and normed linear spaces which are not Banach spaces.	CLO1
II 11 Hours	Linear operators definition and examples, Bounded linear transformations, Normed linear spaces of bounded linear transformations, Concept of algebraic Dual and algebraic reflexive spaces, Dual spaces with examples **Activity:** Students will do results related to bounded linear transformations and Dual spaces.	CLO2
III 12 Hours	**Geometry of Hilbert spaces:** Inner product spaces and Hilber spaces, Further properties of inner product spaces, orthonormal sets, Approximation and optimization, Projections and Riesz Representation theorem for Hilbert spaces. Bounded Operators on Hilbert spaces: Bounded operators and adjoints; normal, unitary and self adjoint operators. **Activity:** Students will do exercises on Hilbert spaces and examples of inner product spaces which are not Hilbert spaces.	CLO3
IV 12 Hours	Hahn-Banach theorem for real linear spaces and its consequences, Reflexive spaces, Solvability of linear equations in Banach spaces. **Three Main Theorems on Banach Space**: BanachSteinhauns theorem (Uniform boundedness theorem) and some of its consequences, Open mapping and closed graph theorems. **Activity:** Students will work on the consequences of Hahn-Banach	CLO4

	theorem and Uniform boundedness theorem.	

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. S. K. Berberian, *Introduction to Hilbert Spaces,* AMS Chelsea Publishing, Rhode Island, 1996.
2. C. Goffman, and G. Pedrick, *First Course in Functional Analysis*, Prentice Hall of India, New Delhi, 1983.
3. E. Kreyszig, *Introductory Functional Analysis with Application*, Willey, 2007.
4. B. V. Limaye, *Functional Analysis,* New Age International (P) Ltd, New Delhi, 1996.
5. F. K. Riesz, and B. S. Nagy, *Functional Analysis*, Dover Publications, 1990.
6. A. H. Siddiqui, *Functional Analysis*, Tata-McGraw Hill, New Delhi, 1987.
7. W. Rudin, *Functional Analysis*, McGraw Hill Education; 2nd edition, 2017.

Course Title: Tensor Algebra
Course Code: MMAT.524
Course type: DEC
Total Hours: 45

L	T	P	Credits
3	0	0	3

Learning outcomes: The students will be able to

CLO1: Explain and use Tensors and operations on Tensors.
CLO2: Understand the metric tensor and angle between vectors.
CLO3: Understand and use Christoffel symbols and Covariant derivative.
CLO4: Understand Differential forms, Wedge product, Exterior derivatives and Lie derivatives.

Units/Hours	Content	Mapping with CLO
I 11 Hours	Contravariant and Covariant vectors, Tensor product of vector spaces, Tensors of second order, Tensor of higher orders, Tensor product of Tensors, Algebraic operations on Tensors, Symmetric and Skew symmetric tensors. **Activity:** Exercises on Contravariant, covariant and mixed tensors of second and higher orders.	CLO1
II 11 Hours	Quotient law, Conjugate symmetric tensor, Relative tensor, Metric tensor, Riemannian metric, fundamental contravariant tensor, length of a curve, Associated tensors, Magnitude of a vector, Angle between two vectors and coordinate curves. **Activity:** Students will be provided exercises on metric tensors and angles between vectors.	CLO2
III 11 Hours	Christoffel symbols, Transformation of Christoffel symbols, Covariant differentiation of scalars, vectors and tensors,, Intrinsic derivative of tensor, Laws of covariant differentiation of tensors, Ricci's Theorem and Covariant constants. **Activity:** Exercise on Christoffel symbols and Covariant derivatives.	CLO3
IV 12 Hours	Differential forms on Euclidean n-space and manifolds, Pullback of Differential forms, Exterior product (Wedge product), Exterior derivative and Lie derivatives. **Activity:** Exercises on Exterior product, Differential forms, Exterior derivative and Lie derivatives.	CLO4

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching / Experimentation /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. D. C. Agrawal, Tensor Calculus and Riemannian geometry, Krishna Prakashan, Meerut, 2003.

2. W. M. Boothby, An Introduction to Differentiable Manifolds and Riemannian Geometry, 2nd edition, Academic Press, New York, 2007.

3. N. J. Hicks, Notes of Differential Geometry, D. Van Nostrand Reinhold Company, New York, 1965.

4. J. M. Lee, Introduction to Smooth Manifolds, GTM, Vol. 218, Springer, New York, 2012.

5. L. W. Tu, An Introduction to Manifolds, Second edition, Springer, 2011.

Course Title: Bio-Mathematics
Course Code: MMAT.525
Course type: DEC
Total Hours: 45

L	T	P	Credits
3	0	0	3

Learning outcomes:
The students will be able to

CLO1. Understand the mechanics, uses, and limitations of the Population Dynamics
CLO2. Learn the role of Age structured Population models
CLO3. Apply stochastic population models in various situations.
CLO4. Learn the basic concepts of SIR epidemic disease models.

Units/ Hours	Contents	Mapping with CLO
I 11 Hours	Population Dynamics: The Malthusian growth ; The Logistic equation; A model of species competition; The Lotka-Volterra predator-prey model; **Activity:** Students will study some population models.	CLO1
II 11 Hours	Age-structured Populations : Fibonacci's rabbits; The golden ratio Φ; The Fibonacci numbers in a sunflower; Rabbits are an age-structured population; Discrete age-structured populations; Continuous age-structured populations; The brood size of a hermaphroditic worm. **Activity:** Students will study some discrete and continuous age structured populations.	CLO2
III 11 Hours	Stochastic Population Growth : A stochastic model of population growth; Asymptotics of large initial populations; Derivation of the deterministic model; Derivation of the normal probability distribution; Simulation of population growth. **Activity:** Students will study some stochastic population growth models.	CLO3
IV 12 Hours	Infectious Disease Modeling: The SI model; The SIS model; The SIR epidemic disease model; Vaccination ; The SIR endemic disease model ; Evolution of virulence. **Activity:** Students will study the SIR epidemic disease models.	CLO4

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. Brauer, F., Driessche, P. V. D. and Wu, J., *Mathematical Epidemiology*, Springer, 2008.
2. Keshet, L. E., *Mathematical Models in Biology*, SIAM, 1988.
3. Giordano, Fox, Horton, *A First Course in Mathematical Modeling*, 5th edition, Cengage, 2013.
4. Clive L. Dym, *Principles of Mathematical Modelling*, Elsevier Press, Second Edition, 2004.
5. Edward A. Bender, *An Introduction to Mathematical Modeling*, Dover, 2000.
6. AlfioQuarteroni, and GervasioPaola. *A Primer on Mathematical Modelling.* Vol. 121. Springer Nature, 2020.

Course Title: Dynamical Systems
Course Code: MMAT.526
Course type: DEC
Total Hours: 45

L	T	P	Credits
3	0	0	3

Learning outcomes:

The students will be able to

CLO1. know about dynamical Systems from an applied and practical point of view.
CLO2. how to compute the behaviour of differential equations as parameters vary.
CLO3. know about the techniques that include bifurcation analysis and computation of normal forms, geometric methods, and the method of averaging.
CLO4. To understand the concept of Local and Global bifurcations.

Units/Hours	Contents	Mapping with CLO
I 11 Hours	**One-Dimensional Flows** **Linear Systems:** linear system theory via eigenvalues and eigenvectors, Fixed Points and Stability, Population Growth, Linear Stability Analysis, Existence and Uniqueness, Impossibility of Oscillations. **Activity:** Students will apply some basics of linear algebra in study of dynamical systems.	CLO1
II 12 Hours	**Bifurcations:** Saddle-Node Bifurcation, Transcritical Bifurcation, Pitchfork Bifurcation, Insect Outbreak **Two-Dimensional Flows** Linear Systems, Classification of Linear Systems **Activity:** Students will check the stability of some dynamical systems by using the concept of bifurcation.	CLO2
III 11 Hours	**Phase Plane:** Phase Portraits, Existence, Uniqueness, and Topological Consequences, Fixed Points and Linearization, Conservative Systems, Reversible Systems, Pendulum, Index Theory Limit Cycles: Introduction to Limit Cyclces, Ruling Out Closed Orbits, Poincare-Bendixson Theorem Hamiltonian Systems in the Plane, Lyapunov Functions and Stability **Activity:** Students will draw the phase portraits of some dynamical systems using some software.	CLO3

IV 11 Hours	**Bifurcations Revisited: Saddle-Node,** Transcritical, and Pitchfork Bifurcations, Hopf Bifurcations: Concept of attractors and repellers, limit cycles and torus, Global Bifurcations of Cycles, Homoclinic & Hetero-clinic points and orbits. **Activity:** Students will draw the phase portraits of some dynamical systems using some software and will study the orbits.	CLO4

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. P. G. Drazin, *Nonlinear Systems*, Cambridge University Press India.
2. R. L. Devaney, *An Introduction to Chaotic Dynamical Systems*, Addison Wesley, 1989.
3. Edward Ott, *Chaos in Dynamical Systems*, Cambridge University Press, 2002
4. G. L. Baker and J. P. Gollub, *Chaotic Dynamics – An Introduction*, Cambridge University Press, 1996.
5. Strogatz, Steven H. *Nonlinear dynamics and chaos with student solutions manual: With applications to physics, biology, chemistry, and engineering*. CRC press, 2018.
6. L. Perko, Differential Equations and Dynamical Systems, Springer Verlag, 1991.
7. S. Lynch, Dynamical systems with applications using Mathematica®. Boston: Birkhäuser, 2007.

Course Title: Numerical Analysis

Course Code: MMAT.404

Total Hours: 45

L	T	P	Credits
3	0	0	3

Learning outcomes:

The students will be able to

- Review the basic concepts of various numerical techniques for a variety of mathematical problems occurring in science and engineering.
- Explain the basic concept of errors .
- Review the numerical techniques for interpolation and approximations with examples.
- Explain the concept of numerical integration and solutions of differential equations.

Units/Hours	Contents	Mapping with CLO
I 11 Hours	**Error Analysis:** Definition and sources of errors, Propagation of errors, Sensitivity and conditioning, Stability and accuracy, Floating-point arithmetic and rounding errors. **Numerical Solutions of Algebraic Equations**: Bisection method. Fixed-point iteration, Newton Raphson's method, Secant method, Convergence and order of convergence **Activity:** Students will explore the use of these methods in solving some real life problems.	CLO1
II 12 Hours	**Linear Systems of Equations:** Gauss elimination and Gauss-Jordan methods, Jacobi and Gauss- Seidel iteration methods. **Polynomial Interpolation:** Interpolating polynomial, Lagrange and Newton divided difference interpolation, Error in interpolation, Finite difference formulas, Hermite Interpolation. **Activity:** Students will make some programmes for implementing these methods using some computer software.	CLO2
III 11 Hours	**Numerical Differentiation and Integration:** Numerical differentiation with finite differences, Trapezoidal rule, Simpson's 1/3 - rule, Simpson's 3/8 rule, Error estimates for Trapezoidal rule and Simpson's rule, Gauss quadrature formulas. **Activity:** Students will make some programmes for implementing these methods using some computer software.	CLO3

IV 11 Hours	**Numerical Solution of Ordinary Differential Equations:** Solution by Taylor series, Picard method of successive approximations, Euler's method, Modified Euler method, Runge- Kutta methods. Finite difference method for boundary value problems. **Activity:** Students will explore the use of these methods in solving some scientific problems.	CLO4

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. K. Atkinson, *An Introduction to Numerical Analysis*, 2nd Edition, John Wiley & Sons, 1989.
2. R. L. Burden and J. D. Faires, *Numerical Analysis*, 9th Edition, Cengage Learning, 2011.
3. C. F. Gerald and P. O. Wheatly,*Applied Numerical Analysis*, 7th Edition, Pearson LPE, 2009.
4. R. S. Gupta, *Elements of Numerical Analysis*, 2nd Edition, Cambridge University Press, 2015.
5. M. K. Jain, S.R.K. Iyengar and R.K. Jain, *Numerical Methods for Scientific and Engineering Computation*, 6th Edition, New Age International, New Delhi, 2015.

S. S. Sastry, *Introductory Methods of Numerical Analysis*, 4th Edition, PHI,

Course Title: Basics of LaTeX (Practical)
Course Code: MMAT.405
Course type: Skill based
Total Hours: 30

L	T	P	Credits
0	0	2	1

Laboratory work:

Students will use software(s) TeXmaker/ Overleaf etc., for performing following activities:

1. Installation of the LaTeX software in Windows and Linux and understanding LaTeX compilation and LaTeX editors.
2. Basic syntax used in LaTeX.
3. Writing mathematical equations, Matrices, Tables, Inclusion of graphics into LaTeX file.
4. Page configurations**:** Title, Abstract, Keywords, Chapter, Sections and Subsections.
5. References and their citations.
6. Labeling of equations, Table of contents, List of figures.
7. Use of Packages**:** amsmath, amssymb, amsthm, amsfonts, graphic.
8. Use of document classes**:** Article, Report, Book, Beamer.
9. Applications of LaTeX in writing reports, books, research papers and thesis.

Transaction mode: Lecture/Demonstration/ Co Operative learning/ programming / Practical/ Group discussion/Team teaching/Experimentation/Tutorial/Problem solving/Self-learning.

Suggested Readings:

1 D. F. Griffiths and D. J. Higham, *Learning LaTeX,* second Edition, Philadelphia, Pennsylvania, SIAM, 1997.

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

3. M. Goossens, F. M. Michel, and S. Alexander, The LaTeX companion, second Edition, Addison-Wesley, 1994.

Course Title: Symbolic Computations and Plotting
Course Code: MMAT.406
Course type: Skill based
Total Hours: 30

L	T	P	Credits
0	0	2	1

1. Solving system of ODEs Numerically: SIR Model (MATLAB: ode45; Mathematica: NDSolve.)

2. Plotting vector fields and phase portraits: Equilibrium points, stability via eigenvalues and Jacobians.

3. **SIR Model for Infectious Diseases:** Implement the Susceptible-Infected-Recovered (SIR) model. Simulate the effects of parameter changes (transmission and recovery rates).

4. **Bifurcation Analysis:** One-parameter bifurcation diagrams (e.g., in logistic growth with harvesting), Effect of reproduction number R0R0 in disease dynamics.

5. **Parameter Estimation :** Use data fitting tools or synthetic data to estimate parameters.

6. **Sensitivity:** Explore sensitivity to initial conditions and parameters.

7. **Data Fitting to Real-World Data**

8. Fit COVID-19/SARS data to SEIR models using least squares.

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. Strogatz, S. H. (2018). *Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry, and Engineering* (2nd ed.). CRC Press.
2. Attaway, S. (2019). *MATLAB: A Practical Introduction to Programming and Problem Solving* (5th ed.). Academic Press.
3. Lynch, S. (2014). *Dynamical Systems with Applications Using MATLAB* (2nd ed.). Birkhäuser.
4. Mangano, S. (2010), *Mathematica Cookbook*. O'Reilly Media.
5. Diekmann, O., & Heesterbeek, J. A. P. (2000). *Mathematical Epidemiology of Infectious Diseases: Model Building, Analysis, and Interpretation*. Wiley.

Course Title: Complex Analysis
Course Code: MMAT.407
Course type: AEC
Total Hours: 45

L	T	P	Credits
3	0	0	3

Learning outcomes:

The students will be able to
CLO1: Recall complex number systems and algebra of complex variables.
CLO2: Illustrate the concept of analytic function and discuss the necessary and sufficient conditions for a function to be analytic.
CLO3: Understand the notion of complex line integral and related results.
CLO4: Discuss Mobius transformations and their properties.
CLO5: Apply ideas of Complex analysis in allied areas.

Units/Hours	Contents	Mapping with CLO
I 10 Hours	Functions of a complex variable, limit, continuity, uniform continuity, differentiability, analytic function, Cauchy- Riemann equations, harmonic functions and harmonic conjugate. **Activity:** Students will make use of Cauchy- Riemann equations to investigate the functions of complex variables which are analytic or not.	CLO1 CL02
II 12 Hours	Complex line integral, Cauchy's theorem, Cauchy-Goursat theorem, Cauchy's integral formula and its generalized form, Cauchy's inequality. Poisson's integral formula (Statement only), Morera's theorem. Liouville's theorem. Contour integral, power series, Taylor's and Laurent's series. **Activity:** Students will find the applications of important theorems like Cauchy's theorem and Cauchy's integral formula. They will also work on various examples of contour integrals.	CLO3
III 12 Hours	Singularities of analytic functions, Fundamental theorem of algebra, zeros of analytic function, poles, residues, residue theorem and its applications to contour integrals. Maximum modulus principle, Schwarz lemma. **Activity:** Students will do the examples related to singularities and poles of analytic functions. They will explore the concept of residues and its applications to solve contour integrals.	CLO4
IV 11 Hours	Meromorphic functions, the argument principle, Rouche's theorem, Mobius transformations and their properties, definition and examples of conformal mappings. **Activity:** Students will explore the concept of Mobius transformations and	CLO5

	its applications in different fields.	

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. H.S. Kasana, *Complex Variables:Theory and Applications,* 2nd Edition, PHI Learning Pvt. Ltd, 2005.
2. R. V. Churchill & J. W. Brown, *Complex Variables and Applications*, 9th Edition, Tata McGraw-Hill, 2014.
3. S. Ponnusamy, *Foundations of Complex Analysis*, 2nd Edition, Narosa Publishing House, 2007.
4. Theodore W. Gamelin, *Complex Analysis*. UTM, Springer-Verlag 2001.
5. W. Tutschke and H.L. Vasudeva, *An Introduction to Complex Analysis, Classical and Modern Approaches*, 1stEdition,CRC Publications, 2004.
6. Rajendra Kumar Sharma, Sudesh Kumari Shah and Asha Gauri Shankar, *Complex Numbers and Theory of Equations*, Anthem Press, 2011.
7. Lars V. Ahlfors, An Introduction to the Theory of Analytic Function of one complex variable, 3rd Edition, Tata McGraw-Hill, 2006.
8. Dennis G. Zill& Patrick D. Shanahan, A First Course in Complex Analysis with Application, 3rd Edition, Jones and Bartlett, 2003.
9. S.Kumaresan*, A Pathway to Complex Analysis, 1st Edition, Techno World Publication, 2021.*

Course Title: Basic Mathematics
Course Code: MMAT.506
Course type: IDC
Total Hours: 30

L	T	P	Credits
2	0	0	2

Learning outcomes:
The students will be able to
CLO1: Define sets and functions with related concepts.
CLO2: Define the concept of functions and relations.
CLO3: Relate the concept of Arithmetic progression and Geometric progression and their sum.
CLO4: Explain the description of algebraic properties of complex numbers.
CLO5: Explore the theory of Matrices and Determinants.

Units/Hours	Contents	Mapping with CLO
I 08 Hours	**Sets**: Basic Definitions, subsets, power set, set operations. Ordered pairs, Cartesian product of sets. **Functions and Relations:** Definition of relation, domain, co-domain and range of a relation. Binary relations, equivalence relations, partition. Function as a special kind of relation from one set to another. Domain, co-domain and range of a function. Composition, inverse. Real valued function of the real variable, constant, identity, Polynomial, rational, Functions. **Activity:** Students will try to find the applications of functions and relations.	CLO1 CL02
II 07 Hours	Sequence and series, Arithmetic Progression (A.P), Arithmetic Mean (A.M), Geometric Progression (G.P), general term of a G.P, sum of n terms of a G.P. Arithmetic and Geometric series, infinite G.P. and its sum. Geometric mean (G .M), relation between A.M and G.M. **Activity:** Students will solve some problems related to these sequences and series.	CLO3
III 08 Hours	Need for complex numbers, especially $\sqrt{-1}$, to be motivated by inability to solve every Quadratic equation. Brief description of algebraic properties of complex numbers. Argand plane and polar representation of complex numbers, Statement of Fundamental Theorem of Algebra, n^{th} roots of unity. **Activity:** Students will solve some problems related to the complex number.	CLO4

IV 07 Hours	Matrices and types of matrices, Operations on Matrices, Determinants of Matrix and Properties of Determinants, Minors and Cofactor and Adjoint of a square matrix, Singular and non-singular Matrices, Inverse of a Matrix, Eigen-values and Eigenvectors, Cayley Hamilton theorem. **Activity:** Students will solve some problems related to the matrices and determinants of a matrix.	CLO5

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Reading:

1. E. Kreyszig, *Advanced Engineering Mathematics*, 9th edition, John Wiley & Sons, Inc., 2006.
2. E. Kreyszig, *Advanced Engineering Mathematics*, 9th edition, John Wiley & Sons, Inc., 2006.
3. G. B. Thomas and R. L. Finney, *Calculus and Analytic Geometry*, 11th edition, Pearson India, 2015.
4. P. K. Jain, *Mathematics: Text book for class XI*, NCERT, 2006.
1. R. K. Jainand S.R.K. Iyengar, *Advanced Engineering Mathematics*, 8th Edition, Narosa Publications, 2002.

Course Title: Vector Analysis (IDC)
Course Code: MMAT.507
Course type: IDC
Total Hours: 30

L	T	P	Credits
2	0	0	2

Learning outcomes:
The students will be able to
CLO1: Explain and use vector dot product and cross product.
CLO2: Understand the Gradient, Divergence and Curl.
CLO3: Understand and use Green's Theorem, Stokes Theorem and Divergence Theorem.
CLO4: Understand Tensors and their applications in Mathematics and allied areas.

Units/Hours	Contents	Mapping with CLO
I 8 Hours	Vectors and Scalars, Vector algebra, Unit vectors, Linear Independence and Linear dependence, Vector fields and scalar fields. Dot and cross product of vectors, Reciprocal set of vectors. Vector differentiation: Ordinary derivative, continuity and differentiability, partial derivatives, Serret-Frenet formulas. **Activity:** To check Linearly independent and Linearly dependent set of vectors, exercises on dot and cross product and vector differentiation.	CLO1
II 7 Hours	Gradient, Directional derivative, Divergence, Curl. Vector Integration: Ordinary integral, line integrals, surface integrals and volume integrals. Divergence Theorem of Gauss, Stokes Theorem, Green's theorem in plane. **Activity:** Exercises on Gradient, Divergence, Curl and Vector integration.	CLO2
III 7 Hours	Transformation of coordinates, orthogonal curvilinear coordinates, arc length and volume elements, Gradient, Divergence and curl in curvilinear coordinates, special orthogonal coordinate systems. **Activity:** Exercises on arc-length, volume, Div. and Curl in Curvilinear coordinates.	CLO3
IV 8 Hours	Contravariant and covariant vectors. Contravariant, Covariant and Mixed Tensors. Tensors of rank greater than two, Tensor fields, Fundamental operations with Tensors, Line element and metric Tensor, Associated Tensors, Christoffel Symbols, Length of a vector, Angle between vectors, Geodesics, Covariant derivative.	CLO4

	Activity: Exercise on Tensors and their applications.	

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching / Experimentation /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. Narayan Shanti, Mittal P.K., A Text Book of Vector Analysis, S Chand & Company, Paperback edition, 2021.
2. Murray Spiegel, Seymour Lipschutz, Dennis Spellman, VECTOR ANALYSIS: Schaum's Outlines Series, McGraw Hill Education, 2nd Edition Paperback ,2017.
3. Louis Brand, Vector and Tensor Analysis, Dover Publications, Paperback edition, 2020.
4. A. I. Borisenko, Vector and Tensor Analysis with Applications, Dover Publications, Paperback edition, 2003.

Course Title: Numerical Methods (IDC)
Course Code: MMAT.508
Course type: IDC
Total Hours: 30

L	T	P	Credits
2	0	0	2

Learning outcomes:
The students will be able to
CLO1. Explain the basic concept of errors .
CLO2. Review the basic concepts of various numerical techniques for a variety of mathematical problems occurring in science and engineering.
CLO3. Review the numerical techniques for interpolation and approximations with examples.
CLO4. Explain the concept of numerical solutions of differential equations.

Units/Hours	Contents	Mapping with CLO
I 7 Hours	**Error Analysis:** Relative error, Truncation error, Roundoff error, Order of approximation, Order of convergence, Propagation. **Activity:** Students will explore the use of error analysis and rounding in some daily life problems like measuring.	CLO1
II 8 Hours	**Roots of Nonlinear Equations:** Bisection method, Secant method, Newton Raphson method, Convergence and order of convergence. **Activity:** Students will explore the use of these methods in solving some real life problems.	CLO2
III 8 Hours	**Linear Systems of Equations:** Gauss elimination and Gauss-Seidel methods. **Interpolation**: Lagrange's Method, Newton's polynomials. **Activity:** Students will explore the use of these methods in solving some real life problems.	CLO3
IV 7 Hours	**Solution of Differential Equations:** Euler's method, Heun's method, Taylor series method, RungeKutta method. **Activity:** Students will explore the use of these methods in solving some scientific problems.	CLO4

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Reading:

1. C. F. Gerald and P. O. Wheatly,*Applied Numerical Analysis*, 7th Edition, Pearson LPE, 2009.
Computation, 6th Edition, New Age International, New Delhi, 2015.
2. J. I. Buchaman and P. R. Turner, *Numerical Methods and Analysis,* Prentice-Hall, 1988.
3. K. Atkinson, *An Introduction to Numerical Analysis,* 2nd Edition, John Wiley & Sons, 2012.
4. M. K. Jain, S.R.K. Iyengar and R.K. Jain, *Numerical Methods for Scientific and Engineering*
5. R. S. Gupta, *Elements of Numerical Analysis*, 2nd Edition, Cambridge University Press, 2015.
6. S. S. Sastry, *Introduction Methods of Numerical Analysis*, 4th Edition, Prentice-Hall, 2005.

Course Title: Linear Programming
Course Code: MMAT.511
Course Type: VAC
Total Hours: 30

L	T	P	Credits
2	0	0	2

Learning outcomes:

The students will be able to

CLO1: Discuss the linear programming problem with formulation.
CLO2: Apply different methods to solve linear programming problems.
CLO3: explore the concept of Duality theory and Sensitivity analysis.
CLO4: Explain transportation problems and assignment problems with their mathematical formulation.

Units/ Hours	**Content**	**Mapping with CLO**
I 8 Hours	Formulation of linear programming problems (LPP). Graphical solution to LPPs. Cases of unique and multiple optimal solutions. Activity: Students will do formulation of Linear programming problems and find the solutions using graphical methods.	CLO1
II 8 Hours	Feasible solution, basic feasible solutions, Optimal solution, Convex sets, Solution of LPP with Simplex methods. Activity: Students will solve linear programming problems with the simplex method.	CLO2
III 6 Hours	The dual problem. Formulation of the dual.Dual Simplex method Activity: Students will do exercises related to dual linear programming problems.	CLO3
IV 8 Hours	Transportation and Assignment Problem: Transportation problems, Formulation of transportation problems, Feasible and optimal solution of transportation problems. Assignment problems. Activity: Students will do exercises on transportation problems and assignment problems.	CLO4

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. H. A. Taha, *Operations Research - An Introduction,* Macmillan Publishing Company Inc., New York, 2006.
2. K .Swarup, P. K. Gupta and Man Mohan, *Operations Research*, Sultan Chand & Sons, New Delhi, 2001.
3. F. S. Hillier and G. J. Lieberman, *Introduction to Operations Research*, McGraw-Hill, New York, 2001.

Course Title: Mathematical Methods
Course Code: MMAT.512
Course type: VAC
Total Hours: 30

L	T	P	Credits
2	0	0	2

Learning outcomes:

CLO1. Students will be able to Integral Transforms.
CLO2. Understand the basic concepts of wavelet transforms.
CLO3. Understand the method of reduction of IVPs BVPs and eigenvalue problems.
CLO4. apply regular and singular perturbation methods.

Units/ Hours	Contents	Mapping with CLO
I **8 Hours**	Integral Transforms: General definition of Integral transforms, Kernels, etc. Development of Fourier integral, Fourier transforms – inversion, Illustration on the use of integral transforms, Laplace, Fourier, Hankel and Mellin transforms to solve ODEs and PDEs - typical examples.	**CLO1**
II **7 Hours**	Discrete orthogonality and Discrete Fourier transform. Wavelets with examples, wavelet transforms. Integral Equations: Definition, Volterra and Fredholm integral equations. Solution by separable kernel, Neumann's series resolvent kernel and transform methods, Convergence for Fredholm and Volterra types. **Activity:** Students will write some differential equations in the form of integral equations and then will solve them.	**CLO2**
III **7 Hours**	Reduction of IVPs BVPs and eigenvalue problems to integral equations. Hilbert Schmidt theorem, Raleigh Ritz and Galerkin methods. Activity: Students will use Raleigh Ritz and Galerkin methods to solve some scientific problems.	**CLO3**

IV **8 Hours**	Regular and singular perturbation methods: Parameter and co-ordinate perturbations. Regular perturbation solution of first and second order differential equations involving constant and variable coefficients. Activity: Students will obtain the regular perturbation solutions of some first and second order differential equations.	**CLO4**

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Suggested Readings:

1. I.N. Sneddon – The use of Integral Transforms, Tata Mc Graw Hill, Publishing Company Ltd, New Delhi, 1974.
2. R.P. Kanwal: Linear integral equations theory and techniques, Academic Press, New York, 1971.
3. C.M. Bender and S.A. Orszag – Advanced mathematical methods for scientists and engineers, McGraw Hill, New York, 1978.

Course Title: Vedic Mathematics and Data Science
Course Code: MMAT.513
Course Type: VAC
Total Hours: 30

L	T	P	Credits
2	0	0	2

Learning outcomes:

The students will be able to

CLO1: Apply the knowledge of Vedic mathematics to understand some properties of statistics.
CLO2: Illustrate various properties of statistics with the help of Vedic mathematics and Computer programming.
CLO3: Explain the basic concepts of data science and linear algebra.
CLO4: Apply the Vedic mathematics sutra to solve the problems of linear algebra.
CLO5: Apply Vedic techniques in conjunction with data science tools and algorithms to tackle real world data analysis challenges.

Units/ Hours	Content	Mapping with CLO
Unit I **8 Hours**	Introduction to Vedic mathematics, Vedic mathematics sutras, and their applications in different fields. Basics of statistics, Mean, Median, Mode,Variance, Probability using Vedic techniques.	CLO 1 CLO2
Unit II **7 Hours**	**Application of Vedic mathematics in statistics**:CurveFitting,Statistical Modelling, Random Variables and Probability Mass/Density Functions, Hypotheses Testing, Linear Regression. Data visualization and manipulation.	CLO2
Unit III **8 hours**	**Basics of data Science:**Solving linear equations using Vedic technique, The solution of Simultaneous linear equations using Vedic technique, Solution of quadratic equations using Vedic technique, Evaluation of determinants, Inversion of Matrices.	CLO 3 CLO 4
Unit IV **7 hours**	Optimization for data Science using Vedic mathematics, Linear Algebra for Data Science, Halfspaces, Eigenvalues, Eigenvectors, Solving Data Analysis Problems using Vedic techniques.	CLO 5

TRANSACTION MODE: Lecture/Demonstration/Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Tutorial/Problem solving/E-team teaching/Self-learning.

Recommended Books:

1. Bharti Krishna Tirtha, Vedic Mathematics, Motilal Banarsi Das, New Delhi, 2015.
2. Bhaskaracharya, Beejganitam, Chokhambba Vidya Bhavan, Varanasi, 2022.
3. S.P. Gupta, Statistical Methods, Sultan Chand & Sons, 2014.
4. Ragunathan Rengasamy, Shankar Narasimhan, Data Science for Engineers, Computer Science and Engineering, NPTEL IIT Madras, 2019.
5. John Zelle, Python Programming: An introduction to computer science, Franklin, Beedle & Associates, 2016.

Semester-III

Course Title: Dissertation Part-I
Course Code: MMAT.599-1

L	T	P	Credits
0	0	40	20

Course Type: Skill Based
Total Hours: 600

Learning outcome:

The students will be able to
CLO1: develop interest in theoretical and practical research.
CLO2: decide their area of research as per their competency.
CLO3: get theoretical and practical knowledge of a specific area of research.
CLO4: prepare them for quality research in any mathematical discipline and allied areas.

Students will have an option to carry out dissertation work in industry, national institutes or Universities in the top 100 NIRF ranking.

Group dissertation may be opted, with a group consisting of a maximum of four students. These students may work using a single approach or multidisciplinary approach. Research projects can be taken up in collaboration with industry or in a group from within the discipline or across the discipline.

Transaction mode: Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Problem solving/Self-learning.

Semester-IV

Course Title: Dissertation Part-II
Course Code: MMAT.599-2

L	T	P	Credits
0	0	40	20

Course Type: Skill Based
Total Hours: 600

Learning outcome:
The students will be able to
CLO1: develop interest in theoretical and practical research.
CLO2: decide their area of research as per their competency.
CLO3: get theoretical and practical knowledge of a specific area of research.
CLO4: prepare themselves for quality research in any mathematical discipline and allied areas.

Students will have an option to carry out dissertation work in industry, national institutes or Universities in the top 100 NIRF ranking.

Group dissertation may be opted, with a group consisting of a maximum of four students. These students may work using a single approach or multidisciplinary approach. Research projects can be taken up in collaboration with industry or in a group from within the discipline or across the discipline.

Transaction mode: Project Method/ Co Operative learning/ Seminar/Group discussion/Team teaching /Problem solving/Self-learning.