Central University of Punjab

Course Scheme & Syllabus
for
Ph. D. Course Work
in
Mathematics

Department of Mathematics and Statistics
School of Basic Sciences

(Batch: 2023-24)

Structure of Course work for PhD in Mathematics

Students can move into the Ph.D. programme after successful completion of Ph. D. Course work during the first two semesters, provided they meet the requirements specified by the university.

Graduate Attributes:

Learners will be able to develop a broad understanding of recent theories, tools and techniques in research areas of Mathematics. They will be able to be competent to apply various Mathematical techniques in a variety of situations. They will be able to independently develop and plan research in various areas of mathematics and allied areas.

Structure of course work for PhD in Mathematics

	Semester I						
	S. No.	**Subject Code**	**Subject Name**	**Credit Hours**			**Course Credits**
				L	**T**	**P**	
Compulsory Courses	1.	MAT.701	Research Methodology	2	0	0	2
	2.	MAT.702	Computer Applications	2	0	0	2
	3.	MAT.751	Research and Publication Ethics	2	0	0	2
	4.	MAT.752	Teaching Assistantship	0	0	2	1
	5.	UNI.753	Curriculum, Pedagogy and Evaluation	1	0	0	1
Opt any two out of the following							
Elective Courses	6.	MAT.704	Symmetries and Differential Equations	4	0	0	4
	7.	MAT.705	Fractional Calculus	4	0	0	4
	8.	MAT.706	Advanced Partial Differential Equations-II	4	0	0	4
	9.	MAT.707	Differential Equations and Boundary-Value Problems	4	0	0	4
	10.	MAT.708	Differentiable Manifolds	4	0	0	4
	11.	MAT.709	Algebraic Topology	4	0	0	4
	12.	MAT.710	Riemannian Geometry	4	0	0	4
	13.	MAT.711	Riemann - Finsler Geometry	4	0	0	4
	14.	MAT.712	General Relativity	4	0	0	4

	15.	MAT.713	Mathematical Modelling in Biological Systems	4	0	0	4
	16.	MAT.714	Dynamical Systems	4	0	0	4
	17.	MAT.715	Linear Algebra	4	0	0	4
	18.	MAT.716	Information Theory	4	0	0	4
	19.	MAT.717	Algebraic Cryptography	4	0	0	4
	20.	MAT.718	Stochastic Differential Equations	4	0	0	4
	21	MAT.719	Fluid Dynamics	4	0	0	4
						Total Credits	**16**

L	T	P	Credits
2	0	0	2

Course Title: Research Methodology
Course Code: STA.701
Total Hours: 30

Learning outcomes:
The student will be able to:

CLO1: Understand meaning, objectives, characteristics, significance, and types of research.

CLO2: Understand the different steps of formulation of research problems.

CLO3: Use latex to write different types of reports.

CLO4: Understand the basics of different bibliography/reference preparation styles.

UNIT/Hours	Content	Mapping with CLO
Unit-I/8 Hours	**Introduction:** Meaning, Objectives, Characteristics, Significance, and Types of Research. **Formulating Research Problem:** Understanding a Research Problem, Selecting the Research Problem, Steps in Formulation of a Research Problem, Formulation of Research Objectives, and Construction of Hypothesis.	**CLO1 CLO2**
Unit-II/ 8 Hours	Installation of the software LaTeX, Understanding LaTeX compilation and LaTeX editors, Basic syntax, Writing mathematical equations, Matrices, Tables, Inclusion of graphics into LaTeX file. **Page configurations:** Title, Abstract, Keywords, Chapter, Sections and Subsections, References and their citations, Labeling of equations, Table of contents, List of figures, List of tables, Page numbering, Generating index.	**CLO3**
Unit-II/7 Hours	**Packages:** amsmath, amssymb, amsthm, amsfonts, hyperrefer, graphic, color, xypic, latexsym, natbib, setspace, multicol, subcaption, url, verbatim, tikz, and geometry. **Classes:** Article, Report, Bresearchook, Letter, Slides, Beamer.	**CLO3**

Unit-IV/7 Hours	**Report Writing:** Types of Reports – Technical and Popular Reports, Significance of Report Writing, Different Steps in Writing Report, Art of Writing Research Proposals, Research Papers, Project Reports, and Dissertations/Thesis; Basics of Citation and Bibliography/Reference Preparation Styles; Report Presentation: Oral and Poster Presentations of Research Reports.	**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. Kothari, C.R. and G. Garg (2014): *Research Methodology*: Methods and Techniques, 3rd ed., New Age International Pvt. Ltd. Publisher
2. Kumar, R. (2014): *Research Methodology – A Step-By-Step Guide for Beginners*, 4th ed., Sage Publications
3. J. Anderson, *Thesis and Assignment Writing*, 4th ed., Wiley, USA, 2001.
4. Catherine Dawson, *Practical Research Methods,* New Delhi, UBS Publishers' Distributors, 2014.
5. L. Lamport. LATEX: A Document Preparation System, User's Guide and Reference Manual. 2nd Edition, Addison Wesley, New York, 1994.
6. Copyright Protection in India [website: http:copyright.gov.in].
7. World Trade Organization [website: www.wto.org].

Course Title: Computer Applications
Course Code: STA.702

L	T	P	Credits
2	0	0	2

Total Hours: 30

Learning outcomes:

The student will be able to:

CLO1: Use different operating systems and their tools easily.

CLO2: Use word processing software, presentation software, spread sheet software

CLO3: Use computers in every field like teaching, industry and research.
CLO4: Use computers in every field like data analysis tools, e-Library.

UNIT/Hours	Content	Mapping with CLO
UNIT- I/8 Hours	Computer Fundamentals: Introduction to Computer, Input devices, Output Devices, Memory (Primary and Secondary), Concept of Hardware and Software, C.P.U., System bus, Motherboard, Ports and Interfaces, Expansion Cards, Ribbon Cables, Memory Chips, Processors, Software: Types of Software, Operating System, User Interface of popular Operating System, Introduction to programming language, Types of Computer.	CLO1
UNIT- II/7 Hours	Computer Network: Introduction to Computer Network, Types of Network: LAN, WAN and MAN, Topologies of Network, Internet concept, WWW. Word Processing: Text creation and Manipulation; Table handling; Spell check, Hyper-linking, Creating Table of Contents and table of figures, Creating and tracking comments, language setting and thesaurus, Header and Footer, Mail Merge, Different views, Creating equations, Page setting, Printing, Shortcut keys.	CLO2
UNIT- III/8 Hours	Presentation Tool: Creating Presentations, Presentation views, working on Slide Transition, Making Notes Pages and Handouts, Drawing and Working with Objects, Using Animations, Running and Controlling a Slide Show, Printing Presentations, and Shortcut keys. Spreadsheet: Entering and editing data in cell, Basic formulas and functions, deleting or inserting cells, deleting or inserting rows and columns, printing of SpreadSheet, Shortcut keys.	CLO3

UNIT IV/7 Hours	Use of Computers in Education and Research: Data analysis tools, e-Library, Search engines related to research, Research paper editing tools like Latex.	CLO4

Transactional Modes: PPT, Video, e-content, Google-drive

Suggested Readings:

1. Sinha, P.K. Computer Fundamentals. BPB Publications.
2. Goel, A., Ray, S. K. 2012. Computers: Basics and Applications. Pearson Education India.
3. Microsoft Office Professional 2013 Step by Step https://ptgmedia.pearsoncmg.com/images/9780735669413/samplepages/9780735669413 13. pdf

Course Title: Research and Publication Ethics
Course Code: MAT.751

L	T	P	Credits
2	0	0	2

Total Hours: 30
Learning outcomes:

The student will be able to:

CLO1: Understand the philosophy and value of publication ethics.
CLO2: Understand ethics with respect to science and research.
CLO3: Identify the predatory publications and open access publications.
CLO4: Use different software and their tools to check plagiarism.

UNIT/Hours	Content	Mapping with CLO
UNIT-I 8 Hours	PHILOSOPHY AND ETHICS: Introduction to philosophy definition, nature and scope, concept, branches; Ethics definition, moral of moral judgements and reactions. SCIENTIFIC CONDUCT: Ethics with respect to science and research; Intellectual honesty and research integrity; Scientific misconducts Falsification, Fabrication, and plagiarism (FFP); Redundant publication duplicate and overlapping publication, salami slicing; Selective reporting and misrepresentation of data	**CLO1**

UNIT-II	PUBLICATION ETHICS: Publication ethics definition	**CLO2**
7 Hours	introduction and importance; Best practices / standards setting initiatives and guidelines: COPE, WAME, etc.; Conflicts of interest; Publication misconduct: definition, concept, problems that lead to unethical behaviour and vice versa, types; violation of publication ethics, authorship and contributorship; identification of publication misconduct, complaints and appeals; predatory publishers and journals	
UNIT-III **8 Hours**	OPEN ACCESS PUBLISHING: Open access publication and initiatives; SHERPA/RoMEO online resource to check publisher copyright & self-archiving policies; software tool to identify predatory publications developed by SPPU; journal finder/ journal suggestion tools viz. JANE, Elsevier Journal Finder, Springer Journal Suggester, etc. PUBLICATION MISCONDUCT: A. Group Discussions: a) Subject specific ethical issues, FFP, authorship; b) Conflicts of interest; c) Complaints and appeals: examples and fraud from India and abroad B. Software tools: Use of plagiarism software like Turnitin, Urkund and other open source software tools.	**CLO3**
UNIT-IV **7 Hours**	DATABASES AND RESEARCH METRICS: A. Databases: a) Indexing databases; b) Citation databases: web of Science, Scopus, etc. B. Research Metrics: a) Impact Factor of journal as per journal Citation Report, SNIP, SJR, IPP, Cite Score b) Metrics, h-index, g-index, i10 index, altmetrics	**CLO4**

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

Suggested Readings:

4. Melville, S., and Goddad, W. (1996). Research Methodology: An Introduction to Science and Engineering students. South Africa: Juta Academic.
5. Kothari, C.R. and G. Garg (2014): *Research Methodology*: Methods and Techniques, 3rd ed., New Age International Pvt. Ltd. Publisher.

Course Title: Teaching Assistantship
Total Hours: 30
Course Code: MAT. 752

L	T	P	Credits
0	0	2	1

Learning Outcome:

At the end of this skill development course, the scholars shall be able to

CLO 1: familiarize themselves with the pedagogical practices of effective classroom delivery and knowledge evaluation system

CLO 2: manage large and small classes using appropriate pedagogical techniques for different types of content

Activities and Evaluation:

1. The scholars shall attend Master degree classes of his/her supervisor to observe the various transaction modes that the supervisor follows in the classroom delivery or transaction process one period per week.
2. The scholars shall be assigned one period per week under the direct supervision of his/her supervisor to teach the Master degree students adopting appropriate teaching strategy(s).
3. The scholars shall be involved in the examination and evaluation system of the Master degree students such as preparation of questions, conduct of examination and preparation of results under the direction of the supervisor.
4. At the end of the semester, the supervisor shall conduct an examination of teaching skills learned by the scholar as per the following **evaluation criteria**:
    - The scholars shall be given a topic relevant to the Master degree course of the current semester as his/her specialization to prepare lessons and deliver in the classroom before the master degree students for one hour (45 minutes teaching + 15 minutes interaction).
    - The scholars shall be evaluated for a total of 50 marks comprising *content knowledge* (10 marks), *explanation and demonstration skills* (10 marks), *communication skills* (10 marks), *teaching techniques employed* (10 marks), and classroom interactions (10).

Course Title: CURRICULUM, PEDAGOGY AND EVALUATION
Course Code: UNIV.753
Total Hours: 15
Learning outcomes:

L	T	P	Credits
1	0	0	1

After completion of the course, scholars shall be able to:

CLO1: analyze the principles and bases of curriculum design and development
CLO2: examine the processes involved in curriculum development
CLO3: develop the skills of adopting innovative pedagogies and conducting students' assessment
CLO4: develop curriculum of a specific course/programme.

UNIT/Hours	**Content**	**Mapping with CLO**
UNIT-I **4 Hours**	**Bases and Principles of Curriculum** Curriculum: Concept and Principles of curriculum development, Foundations of Curriculum Development. Types of Curriculum Designs- Subject centered, learner centered, experience centered and core curriculum. Designing local, national, regional and global specific curriculum. Choice Based Credit System and its implementation.	**CLO1**
UNIT-II **4 Hours**	**Curriculum Development** Process of Curriculum Development: Formulation of graduate attributes, course/learning outcomes, content selection, organization of content and learning experiences, transaction process. Comparison among Interdisciplinary, multidisciplinary and trans-disciplinary approaches to curriculum.	**CLO2**
III **3 Hours**	**Curriculum and Pedagogy** Conceptual understanding of Pedagogy. Pedagogies: Peeragogy, Cybergogy and Heutagogy with special emphasis on Blended learning, Flipped learning, Dialogue, cooperative and collaborative learning Three e-techniques: Moodle, Edmodo, Google classroom	**CLO3**
IV **4 Hours**	**Learners' Assessment** Assessment Preparation: Concept, purpose, and principles of preparing objective and subjective questions. Conducting Assessment: Modes of conducting assessment – offline and online; use of ICT in conducting assessments. Evaluation: Formative and Summative assessments, Outcome based assessment, and scoring criteria.	**CLO4**

Transaction Mode
Lecture, dialogue, peer group discussion, workshop

Evaluation criteria

There shall be an end term evaluation of the course for 50 marks for duration of 2 hours. The course coordinator shall conduct the evaluation.

1. Allyn, B., Beane, J. A., Conrad, E. P., & Samuel J. A., (1986). Curriculum Planning and Development. Boston: Allyn & Bacon.
2. Brady, L. (1995). Curriculum Development. Prentice Hall: Delhi. National Council of Educational Research and Training.
3. Deng, Z. (2007). Knowing the subject matter of science curriculum, Journal of Curriculum Studies, 39(5), 503-535. https://doi.org/10.1080/00220270701305362.
4. Gronlund, N. E. & Linn, R. L. (2003). Measurement and Assessment in teaching. Singapore: Pearson Education.
5. McNeil, J. D. (1990). Curriculum: A Comprehensive Introduction, London: Scott, Foreman/Little.
6. Nehru, R. S. S. (2015). Principles of Curriculum. New Delhi: APH Publishing Corporation.
7. Oliva, P. F. (2001). Developing the curriculum (Fifth Ed.). New York, NY: Longman Stein, J. and Graham, C. (2014). Essentials for Blended Learning: A Standards-Based Guide. New York, NY: Routledge.

Web Resources

8. https://www.westernsydney.edu.au/ data/assets/pdf_file/0004/467095/Fundamentals_of_Blende d_Learning.pdf
9. https://www.uhd.edu/academics/university-college/centers-offices/teaching-learning- excellence/Pages/Principles-of-a-Flipped-Classroom.aspx
10. http://leerwegdialoog.nl/wp-content/uploads/2018/06/180621-Article-The-Basic-Principles-of- Dialogue-by-Renate-van-der-Veen-and-Olga-Plokhooij.pdf

Course Title: Symmetries and Differential Equations

Course Code: MAT.704

Total Hours: 60

L	T	P	Credits
4	0	0	4

Learning outcomes:.

The student will be able to:

CLO1. Know the basics of dimensional analysis and Lie group of transformations.

CLO2. Learn the basic applications of the Lie group of transformation for solving ordinary and partial differential equations.

CLO3. Learn the concept of extended infinitesimal transformations.

CLO4. Understand the basic concept of multi-parameter Lie groups of transformations.

UNIT/Hours	Content	Mapping with CLO
UNIT-I **15 Hours**	Dimensional Analysis: Buckingham Pi-theorem, Assumptions behind dimensional analysis, Conclusions from dimensional analysis, Proof of the Buckingham Pi-theorem and examples, Application of dimensional analysis to partial differential equations, Generalization of dimensional analysis, Invariance of partial differential equations under scaling of variables	**CLO1**
UNIT-II **15 Hours**	Lie Group of Transformations: Groups, Examples of groups, Groups of transformations, One-parameter Lie group of transformations, Examples of one-parameter Lie groups of transformations, Infinitesimal transformations: First fundamental theorem of Lie, Infinitesimal generators, Invariant functions.	**CLO2**
UNIT-III **15 Hours**	Canonical coordinates, Invariant surfaces, Invariant curves, Invariant points, Extended transformations: Extended group transformations-one dependent and one independent variable, Extended infinitesimal transformations-one dependent and one independent variable, Extended transformations-one dependent and n-independent variables.	**CLO3**
UNIT-IV **15 Hours**	Multi-parameter Lie groups of transformations; Lie algebras, r-parameter Lie groups of transformations, Lie algebras, Examples of Lie algebras, Solvable Lie algebras.	**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. G. W. Bluman and A. C. Anco, *Symmetry and Integration Methods for Differential Equations*, Appl. Math. Sci., 154, Springer, New York, 2002.
2. G. W. Bluman and S. Kumei, *Symmetries and Differential Equations*, Appl. Math.Sci., Springer-Berlin, 1989.
3. P. J. Olver, *Applications of Lie Groups to Differential Equations*, Springer-Verlag, New York 1993.
4. L. V. Ovsiannikov, *Group Properties of Differential Equations*, Novosibirsk, Moscow, 1962.

Course Title: Fractional Calculus

L	T	P	Credit

			s
4	0	0	4

Course Code: MAT.705

Total Hours: 60

Learning outcomes:.

The student will be able to:

CLO1. Learn the basics of fractional calculus.

CLO2. Learn the different types of fractional derivatives.

CLO3. Understand the concept of linear fractional differential equations.

CLO4. Apply different techniques for solving fractional differential equations.

UNIT/Hours	Content	Mapping with CLO
UNIT-I 15 Hours	**Special Functions of Fractional Calculus:** Gamma function, Some properties of Gamma function, Beta function, Contour integral representation. Fractional derivatives and integrals, GrunwaldLetnikov Fractional derivatives, Riemann-Liouville fractional derivatives, Caputo's fractional derivative, The Leibniz rule for fractional derivatives, Geometric and physical interpretation of fractional integration and fractional differentiation.	**CLO1**
UNIT-II 15 Hours	Sequential fractional derivatives. Left and right fractional derivatives. Properties of fractional derivatives. Laplace transforms of fractional derivatives. Fourier transforms of fractional derivatives. Mellin transforms of fractional derivatives.	**CLO2**
UNIT-III 15 Hours	**Linear Fractional Differential Equations:** Fractional differential equation of a general form. Existence and uniqueness theorem as a method of solution. Dependence of a solution on initial conditions. The Laplace transforms method. Standard fractional differential equations. Sequential fractional differential equations.	**CLO3**
UNIT-IV 15 Hours	**Fractional Differential Equations:** Introduction, Linearly independent solutions, Solutions of the homogeneous equations, Solution of the non-homogeneous fractional differential equations, Reduction of fractional differential equations to ordinary differential equations. Semi differential	**CLO4**

	equations.	

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. B. Oldham & J. Spanier, *The Fractional Calculus: Theory and Applications of Differentiation and Integration to Arbitrary Order*, Dover Publications Inc, 2006.
2. K. S. Miller & B. Ross., *An Introduction to the Fractional Calculus and Fractional Differential Equations Hardcover*, Wiley Blackwell, 1993.
3. I. Podlubny, *Fractional Differential Equations*, Academic Press, 1998.

Course Title: Advanced Partial Differential Equations-II

Course Code: MAT.706

L	T	P	Credits
4	0	0	4

Total Hours: 60

The students will be able to

CLO1. use smooth functions for approximations.

CLO2. understand the basic concepts of Weak solutions of elliptic boundary value problems

CLO3. study scientific evolution equations.

CLO4. learn the conditions for existence of minimizers

Units/ Hours	Contents	Mapping with CLO
UNIT-I 15 Hours	**Distribution**: Test functions and distributions, examples, operations on distributions, supports and singular supports, convolution, fundamental solutions, fourier transform, Schwartz space, tempered distributions. **Sobolev Spaces**: Basic properties, approximation by smooth functions, extension theorems, compactness theorems, dual spaces, functional order spaces, trace spaces, trace theory, inclusion theorem. **Activity:** Students will use smooth functions for	**CLO1**

	approximations.	
UNIT-II 15 Hours	**Weak solutions of elliptic boundary value problems**: variational problems, weak formulation of elliptic PDE, regularity, Galerkin method, Maximum principles, eigenvalue problems, Introduction to finite element methods. **Activity:** Students will obtain weak solutions of some elliptic boundary value problems.	**CLO2**
UNIT-III 15 Hours	**Evolution Equations**: unbounded linear operators, C_0 – semigroups, Hille-Yosida theorem, contraction semigroup on Hilbert spaces, heat equation, wave equation, Schrödinger equation, in homogeneous equations. **Activity:** Students will study scientific evolution equations.	**CLO3**
UNIT-IV 15 Hours	**Calculus of Variations**: Euler-Lagrange equation, second variation, existence of minimizers (coactivity, lower semi-continuity, convexity), regularity, constraints (nonlinear eigenvalue problems, variational inequalities, harmonic maps, incompressibility), critical points (mountain pass theorem and applications to elliptic PDE). **Activity:** Students will check the conditions for existence of minimizers.	**CLO4**

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

Suggested Books:

1. S. Kesavan, *Topics in Functional Analysis and Application*, Wiley-Eastern, New International, New Delhi, 1999.
2. L. C. Evans, *Partial Differential Equations. Graduate Studies in Mathematics*, American Mathematical Society, 2nd Edition, Indian Reprint, 2014.
3. Rao, K. S., *Introduction to Partial Differential Equation*, 2nd Edition, PHI Learning Pvt. Ltd. 2010.

4. Amarnath, T., *An Elementary Course in Partial Differential Equations*, 2nd Edition, Narosa Publishing House 2012.
5. Sneddon, I. N., *Elements of Partial Differential Equations*, McGraw-Hill Book Company, New York 1988.

Course Title: Differential Equations and Boundary-Value Problems

Course Code: MAT.707

L	T	P	Credits
4	0	0	4

Total Hours: 60

Learning outcomes:.

The students will be able to

CLO1: Review the basic concepts of Existence and uniqueness of solutions of ODEs.

CLO2: Explain the stability and Liapunov functions for Non-linear system of ODE.

CLO3: Classify the First-order PDEs, into cauchy problems and second order PDEs into Parabolic, Hyperbolic and Elliptic.

CLO4: Review the basic concepts of Sobolev Spaces and the system of conservation laws.

Learning Outcomes: The objective of this course is to ensure that a student learns basic differential equations and boundary value problems.

Units/ Hours	Contents	Mapping with CLO
UNIT-I **15 Hours**	Existence and uniqueness of solutions of ODEs, power series solution, singular points, some special functions. Non-linear system of ODE: preliminary concepts and definitions, the fundamental existence-uniqueness results, dependence on initial conditions and parameters, the maximum interval of existence. **Activity:** Students will do some exercise on Existence and uniqueness of solutions of ODEs.	**CLO1**

UNIT-II **15 Hours**	Linearlization, stability and Liapunov functions, saddle, nodes, foci and centers, normal form theory and Hamiltonian systems. Boundary value problems: Green's function method, Sturm-Liouville problem. **Activity:** Students will explore the stability and Liapunov functions for Non-linear system of ODE.	**CLO2**
UNIT-III **15 Hours**	First-order PDEs, cauchy problem, method of characteristics, second-order PDEs, classification, characteristics and canonical forms. Elliptic boundary value problems: maximum principle, Green's function. **Acitivity:** students will apply the First-order PDEs into cauchy problems and second order PDEs into Parabolic, Hyperbolic and Elliptic.	**CLO3**
UNIT-IV **15 Hours**	Sobolev spaces, variational formulations, weak solutions, Lax-Milgram theorem, trace theorem, Poincarénequality, energy estimates, Fredholm alternative, regularity estimates, system of conservation laws, entropy criteria. **Acitivity:** Students will study the Sobolev Spaces and the system of conservation laws.	**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. L. Perko, *Differential Equations and Dynamical Systems*, 3rd Edition Springer-Verlag New York, 2001.
2. J. Guckenheimer, P. Holmes, *Nonlinear Oscillations, Dynamical Systems, and Bifurcations of Vector Fields*, 1st Edition, Springer-Verlag, New York, 1983.
3. S. Wiggins, *Introduction to Applied Nonlinear Dynamical Systems and Chaos*, 2nd Edition, Springer-Verlag, New York, 1990.
4. L. C. Evans, *Partial Differential Equations, Graduate Studies in Mathematics*, Vol. 19, American Mathematical Society, Providence, 1998.
5. R. C. McOwen, *Partial Differential Equations-Methods and Applications*, 2nd Edition Pearson Education Inc., Indian Reprint 2002.
6. S. J. Farlow, *Partial Differential Equations for Scientists and Engineers*, Dover Publications, New York, 1982.

Course Title: Differentiable Manifolds
Course Code: MAT.708
Total Hours: 60

L	T	P	Credits
4	0	0	4

Learning Outcomes:
The students will be able to
CLO1: learn the basics of Differentiable Manifolds.
CLO2: appreciate the topics covered in allied courses like Algebraic Topology, Riemannian geometry and Riemann-Finsler geometry.
CLO3: adequately prepared for pursuing research in above mentioned topics
CLO4: Understand the fundamentals of Tensor algebra.

UNIT/Hours	Content	Mapping with CLO
UNIT-I **14 Hours**	Topological manifolds, Charts, Atlases, Smooth manifolds, Examples of smooth manifolds, Manifolds with boundary, Smooth functions on a manifold, Smooth maps between manifolds, Diffeomorphism, Smoothness in terms of components, Examples of smooth maps, Smooth covering maps, Partition of unity and Bump functions.	**CLO1** **CLO2** **CLO3**
UNIT-II **16 Hours**	Tangent vectors, Tangent space and Tangent bundle, The Differential of a map, Computations in coordinates, Velocity vectors of curves, Maps of constant rank, Embeddings, Submersions, and Immersions, Embedded submanifolds, Immersed submanifolds, Restricting maps to submanifolds, Tangent space to submanifolds. Sard's theorem, The Whitney embedding theorem (statement only).	**CLO1** **CLO2** **CLO3**
UNIT-III **16 Hours**	Topological groups, Lie groups, Lie group homomorphisms, Lie subgroups, Group actions and Equivariant maps, Vector fields, Vectorfields and smooth maps, Integral curves of vector fields, Lie brackets, The Lie algebra of a Lie group.	**CLO1** **CLO2** **CLO3**
UNIT-IV **14 Hours**	Differential forms on Euclidean n-space, Differential forms on manifolds, The Exterior algebra, Exterior product, Exterior derivative, Pullback of a map, Interior product and Lie derivative, The Cartan formula and properties of Lie derivatives.	**CLO1** **CLO2** **CLO3** **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, 2007.
2. S. S. Chern, W. H. Chen and K. S. Lam, *Lectures on Differential Geometry*, World Scientific Publishing Co. Pvt. Ltd., 2022.
3. L. Conlon, *Differentiable Manifolds*, 2nd edition, Birkhauser Boston, Cambridge, MA, 2011.
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, 2021.
7. L. W. Tu, *An Introduction to Manifolds*, Second edition, Springer, 2011.
8. F. Warner, *Foundations of Differentiable Manifolds and Lie Groups*, GTM, 94, Springer, New York, 1983.

Course Title: Algebraic Topology
Course Code: MAT.709
Total Hours: 60

L	T	P	Credits
4	0	0	4

Learning outcomes:

The students will be able to

CLO1: Understand the fundamental concept of Homotopy theory to pursue research.

CLO2: Develop the knowledge of fundamental groups and covering spaces with related properties.

CLO3: Construct homotopies and prove homotopy equivalence.

CLO4: Understand free products and free groups and their applications.

CLO5: Understand the classification of covering spaces.

CLO6: apply his or her knowledge of algebraic topology to formulate and solve problems of a geometrical and topological nature in mathematics.

UNIT/Hours	Content	Mapping with CLO
UNIT-I **15 Hours**	The Fundamental group: Homotopy of paths, Homotopy classes, The Fundamental group, Change of base point, Topological invariance, Covering spaces, The Fundamental group of the circle.	**CLO1** **CLO2** **CLO3** **CLO6**
UNIT-II **15 Hours**	Retractions and fixed points, No Retraction Theorem, The Fundamental theorem of Algebra, The Borsuk-Ulam theorem, The Bisection theorem, Deformation Retracts and Homotopy type,	**CLO1** **CLO2** **CLO3** **CLO6**

	Homotopy invariance.	
UNIT-III **15 Hours**	Direct sums of Abelian Groups, Free products of groups, Uniqueness of free products, Least normal subgroups, Free groups, Generators and relations, The Seifert-Van Kampen theorem, The Fundamental group of a wedge of circles.	**CLO4** **CLO6**
UNIT-IV **15 Hours**	Classification of covering spaces: Equivalence of covering spaces, The general lifting lemma, The universal covering space, Covering transformation, Existence of covering spaces.	**CLO5** **CLO6**

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,* UTM, Springer, 2000.
2. S. Deo, *Algebraic Topology: A Primer (Texts and Readings in Mathematics),* Hindustan Book Agency, 2003.
3. M. J. Greenberg and J. R. Harper, *Algebraic Topology:* A First Course, CRC Press; 1st edition, 2018.
4. A. Hatcher, *Algebraic Topology*, Cambridge University Press, 2009.
5. W. S. Massey, *A Basic Course in Algebraic Topology,* SPRINGER (SIE), 2007.
6. J. R. Munkres, *Elements of Algebraic Topology*, Perseus Books, 1995.
7. J. J. Rotman, *An Introduction to Algebraic Topology*, *Text in Mathematics, No. 119*, Springer, New York, 2004.
8. E. H. Spanier, *Algebraic Topology (2nd edition*), Springer-Verlag, New York, 2000.

Course Title: Riemannian Geometry
Course Code: MAT.710
Total Hours: 60

L	T	P	Credits
4	0	0	4

Learning outcomes:

The students will be able to

CLO1: learn basic concepts of Riemannian geometry.

CLO2: appreciate the topics covered in allied courses like, Riemann-Finsler geometry, Mathematical Physics and their applications in allied areas.

CLO3: adequately prepared for pursuing research in Riemannian geometry and its allied areas

CLO4: understand the fundamentals of Theory of General Relativity.

Units/Hours	Content	Mapping with CLO
UNIT-I **14 Hours**	Review of differentiable manifolds and vector fields, Covariant differentiation of vector fields and affine connection, Riemannian metric, Riemannian	**CLO1** **CLO2** **CLO3**

	manifolds, Riemannian connection, Fundamental theorem of Riemannian geometry via Koszul's formula.	**CLO4**
UNIT-II **16 Hours**	Tensors and tensor fields (Riemannian metric as the most significant example), Tensorial property, Covariant differentiation of tensor fields, Riemann curvature tensor, Ricci tensor, Sectional, Ricci and scalar curvatures, Isometries, Notion of covering spaces, Pull-back metrics via diffeomorphisms.	**CLO1** **CLO2** **CLO3** **CLO4**
UNIT-III **16 Hours**	Covariant differentiation of a vector field along a curve with specific examples, Arc length and energy of a piecewise smooth curve, Geodesics as length minimizing curves, First variation of arc length, To show that geodesics are critical points of the fixed end point first variation formula, Exponential map, Geodesic completeness, Geodesic normal coordinates, Hopf-Rinow theorem (statement only), Geodesic variations, Jacobi fields and Gauss lemma.	**CLO1** **CLO2** **CLO3** **CLO4**
UNIT-IV **14 Hours**	Second variation formula, The index form (Jacobi fields as minimizers of the index form), Global differential geometry, Spaces of constant sectional curvature, Bonnet-Myers theorem, Cartan-Hadamard theorem, Cartan's theorems (on determination of metric by curvature).	**CLO1** **CLO2** **CLO3** **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. Berger, *A Panoramic View of Riemannian Geometry*, Springer; 1st Edition, 2003. Corr. 2nd printing, 2011.
2. W. M. Boothby, *An Introduction to Differentiable Manifolds and Riemannian Geometry*, 2nd Edition, Academic Press, New York, 2007.
3. S. S. Chern, W. H. Chen and K. S. Lam, *Lectures on Differential Geometry*, World Scientific Publishing, 2022.
4. Manfredo P. Do Carmo and Francis Flaherty, *Riemannian Geometry: Theory and Applications*, Birkhausker Boston, 2011.
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 Riemannian Manifolds-176*, GTM, Springer, 2021.
7. B. O' Neill, *Semi-Riemannian Geometry with Applications to Relativity*, Academic Press, New York, 1983.

Course Title: Riemann-Finsler Geometry

L	T	P	Credits
4	0	0	4

Course Code: MAT.711

Total Hours: 60

Learning Outcomes: The objective of this course is to enable the students, concepts of Riemann-Finsler geometry so that they can pursue research in this area.

Learning outcomes:

The students will be able to

CLO1: learn basic concepts of Riemann-Finsler geometry.

CLO2: appreciate the topics covered in allied courses like Riemannian geometry, Mathematical Physics and their applications in allied areas.

CLO3: adequately prepared for pursuing research in Riemann-Finsler geometry.

CLO4: pursue further studies on Homogeneous Finsler Spaces.

Units/Hours	Content	Mapping with CLO
UNIT-I **14 Hours**	Minkowski norms, Euler's theorem, Fundamental inequality and its interpretation, Finsler structures: definitions and conventions, Examples: Minkowski and locally Minkowski spaces, Riemannian manifolds, Randers spaces, Berwald spaces, Finsler spaces of constant flag curvature. Fundamental metric tensor and Cartan tensor.	**CLO1** **CLO2** **CLO3** **CLO4**
UNIT-II **16 Hours**	Vector bundle, Nonlinear connection on slit tangent bundle, Chern connection, Structure equations, Horizontal and vertical covariant derivatives, hh-, hv-, vv-curvatures, Bianchi identities and their consequences, Ricci identities, Geodesic spray coefficients, Flag curvature: Definition, example and its predecessor, Schur's lemma.	**CLO1** **CLO2** **CLO3** **CLO4**
UNIT-III **16 Hours**	Rund's differential equation and its consequence, Criterion for strong convexity, Berwald frame, Moore frame, Geometrical setup on sphere bundle, Cartan scalar(I), Landsberg scalar(J) and Gaussian curvature(K), Riemannian arc length of indicatrix, Gauss Bonnet theorem for Landsberg surfaces.	**CLO1** **CLO2** **CLO3** **CLO4**
UNIT-IV **14 Hours**	Geodesics: Sprays, shortest paths. Projectively equivalent Finsler metrics, Projectively flat metrics, Parallel vector fields, Parallel translations, Berwald metrics, Landsberg metrics, Distortion and S-curvature, Randers metric of isotropic S-curvature.	**CLO1** **CLO2** **CLO3** **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. L. Antonelli (ed.), *Handbook of Finsler Geometry*, Kluwer Academic Publishers, Dordrecht, The Netherlands, 2003.
2. D. Bao, S. S. Chern, Z. Shen, *An Introduction to Riemann Finsler Geometry, Graduate texts in Mathematics 200*, Springer-Verlag, New York, 2012.
3. Xinyue Cheng and Zhongmin Shen, *Finsler geometry-An Approach via Randers spaces*, First Edition, Springer Berlin Heidelberg, 2013.
4. S. S. Chern and Z. Shen, *Riemann-Finsler Geometry,* Nankai Tracts in Mathematics, Vol. 6. World Scientific Publishing Co. Pvt. Ltd., 2005.
5. M. Matsumoto, *Foundations of Finsler Geometry and Special Finsler Spaces*, Kaisheisha press, Saikawa, Otsu, 520, Japan, (1986).
6. Z. Shen, *Lectures on Finsler geometry*, World Scientific Press, 2001.
7. Y. B. Shen and Z. Shen, *Introduction to Modern Finsler Geometry*, World Scientific Publishing Co. Pvt. Ltd., 2016.
8. H. Rund, The Differential Geometry of Finsler Spaces:101, Springer-Verlag, 2012.

Course Title: General Relativity

Course Code: MAT.712

Total Hours: 60

L	T	P	Credits
4	0	0	4

Learning Outcomes:

The students will be able to

CLO1: learn basic concepts of Tensor Algebra and Riemannian metric.

CLO2: understand the concept of Special theory of relativity.

CLO3: obtain the spherically symmetric solutions of Einstein field equations

CLO4: learn the large scale structure of the universe by studying cosmology.

Units/ Hours	Contents	Mapping with CLO
UNIT-I 15 Hours	Transformation of coordinates, Tensor Algebra, Smooth manifolds: Definition and examples, vector fields, Lie brackets and Lie derivatives. Riemannian metric, parallel transport, covariant derivative, affine connection, Riemannian connection, Geodesics, Riemann curvature tensor and its symmetric properties, Ricci tensor, Bianchi identities, Einstein tensor.	**CLO1**
UNIT-II 15 Hours	Postulates of Special Theory of Relativity, Lorentz Transformation and consequences, Minkowski Diagram, Four dimensional spacetime continuum, Four vector formulation. Transition of Special to General Theory of Relativity, Principle of covariance, Equivalence Principle and consequences, Stress	**CLO2**

	Energy Tensor, Einstein Field Equations and Newtonian limit.	
UNIT-III 15 Hours	Spherically symmetric solution to Einstein Field Equation in free space and in matter, Schwarzshild line element. Schwarzschild Black Holes. Equation of Planetary Orbits, Crucial tests of General Theory of Relativity, Advance of Perihelion, Gravitational bending of light and Gravitational Redshift.	**CLO3**
UNIT-IV 15 Hours	Cosmology: Large scale structure of Universe, Galactic Densities and the darkness of the Night Sky, Galactic Number Counts, Olber's paradox, Cosmological principles, Relativistic Universe and models. Einstein and de-Sitter models of static universe, Dynamical Universe, Comoving time, Red Shifts and Horizons, Friedmann-Robertson-Walker line element, Open and Closed Universe, Hubbles law, Early Universe.	**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. R. Adler, M. Bazin and M. Schiffer, Introduction to General Relativity, McGraw Hill, 1965.
2. S. Caroll, Spacetime and geometry: an introduction to general relativity, Addison Wesley, 2004.
3. J. B. Hartle, Gravity: an introduction to Einstein's general relativity, Pearson education, 2003.
4. R. D. Inverno, Introducing Einstein's relativity, Oxford university press, 2005.
5. C. W. Misner, K. S. Thorne and J. A. Wheeler, Gravitation, W. H. Freeman and Co. 1973.
6. J. V. Narlikar, General Relativity and Cosmology, Macmillan, 1978.
7. A. S. Ramsey, Newtonian Attraction, Cambridge University Press, 1964.
8. B. F. Schutz, A First Course in General Relativity, Cambridge University Press, 2012.
9. S. Weinberg, Gravitation and cosmology: principles and applications of the general theory of relativity, John wiley and Sons, 2004.

Course Title: Mathematical Modelling in Biological Systems

Course Code: MAT.713

Total Hours: 60

L	T	P	Credits
4	0	0	4

Learning outcomes:

The students will be able to

CLO1. Understand the basic concepts, mathematical modelling in biological systems.
CLO2. Create models for real life problems.

CLO3. Learn the technique of solving the difference equations
CLO4. Learn the application of various epidemic models

Units/ Hours	Contents	Mapping with CLO
UNIT-I 15 Hours	Introduction to mathematical models. Stability of linear and nonlinear systems. Phase Plane method and qualitative solutions. Continuous Models: growth models, harvesting model, delay models, age distribution models, interaction populations models	**CLO1**
UNIT-II 15 Hours	Models for molecular events. Limit cycles, oscillations and excitable systems. May's Model, ratio dependent model of two interacting species, two prey-one predator system with ratio- dependent.	**CLO2**
UNIT-III 15 Hours	Discrete dynamics: linear models, graphical solutions of difference equations, equilibrium analysis, periodic-doubling and chaotic behavior, system of two difference equations. Food chain and Food web models. Stage-structured models. Introduction to Modelling Epidemics: Plague, Measles, T.V., Cancer, Malaria	**CLO3**
UNIT-IV 15 Hours	Simple Epidemics Models: SI, SIS, SIR, SIRS, SEIS, SEIR. Stability of simple epidemics models. Models for disease with no immunity. Compartment Models in Epidemiology. Models for demographic effect, Disease as population control, Infective period of fixed length. Impulsive control in continuous and Discrete systems. Pulse vaccination epidemic 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. S.A. Levin, Frontiers in Mathematical Biology, Springer-Verlag, 1994.

2. Nicholas F. Britton, Essential Mathematical Biology, Springer, 2002.
3. Leach Edelstein-Keshet, Mathematical Models in Biology, SIAM's Classics in Applied Mathematics, 1988.
4. J.D. Murray, Mathematical Biology, Springer (3rd Ed.), 2002.
5. Fred Brauer and Carlos Castillo-Chavez, Mathematical Models in Population Biology and Epidemiology.
6. Mark Kot, Elements of Mathematical Ecology, Cambridge University Press, 2001.
7. N.T.J. Bailey, The mathematical theory of infectious diseases and its applications. 2nd edition, 1975.

Course Title: Dynamical Systems

Course Code: MAT.714

Total Hours: 60

L	T	P	Credits
4	0	0	4

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
UNIT-I 15 Hours	**Basic Concepts**: Discrete and continuous dynamical systems. Linear and nonlinear systems and principle of superposition. Linear and nonlinear forces. Concepts of evolution, iterations, orbits, fixed points, periodic and aperiodic (chaotic) orbits. Basics of Linear Algebra: Symmetric & Skew-symmetric matrices, matrix norm and singular value decomposition. Eigenvalues, eigenvectors, and dynamical interpretation. **Activity:** Students will apply some basics of linear algebra in study of dynamical systems.	**CLO1**

UNIT-II **15 Hours**	Canonical forms; simple and non-simple canonical systems. System of Equations. **Stability Analysis**: Stability of a fixed point and classification equilibrium states (for both discrete and continuous systems). Concept of bifurcation and classification of bifurcations. Concepts of Lyapunov stability & Asymptotic stability of orbits. **Activity:** Students will check the stability of some dynamical systems by using the concept of bifurcation.	**CLO2**
UNIT-III **15 Hours**	Phase Portraits of various Linear and Nonlinear systems. Hopf bifurcation. Concept of attractors and repellers, limit cycles and torus. **Phenomena of Bifurcation**: Definition of bifurcation. Bifurcations in one, two and higher dimensional systems. **Activity:** Students will draw the phase portraits of some dynamical systems using some software.	**CLO3**
UNIT-IV **15 Hours**	Hopf, Period doubling, Saddle node, Transcritical bifurcations. Feigenbaum's number. Local and Global bifurcations. Homoclinic & Hetero-clinic points and orbits. Poincaré-Bendixson Theorem. Conservative and Dissipative Systems. **Activity:** Students will draw the phase portraits of some dynamical systems using some software and will study the orbits.	**CLO4**

Suggested Readings:

1. Differential Equations and Dynamical Systems by Lawrence Perko, Springer-Verlag, 2006.
2. Differential Equations, Dynamical Systems and an Introduction to Chaos by Morris W. Hirsch, Stephen Smale and Robert L. Devaney, Academic Press, 2013
3. Dynamical Systems and Numerical Analysis by A.M. Stuart and A.R. Humphries, Cambridge University Press, 1998.
4. Fractals Everywhere by M. F. Barnsley, 2nd edition, Academic Press, 1995
5. An introduction to chaotic dynamical system by Robert L. Devaney, Addison Wesley publishing house Co inc. 1989.
6. Nonlinear Dynamics and Chaos with Applications to Physics, Biology, Chemistry and Engineering, by Steven H. Strogatz, Westview Press.
7. A. F. Beardon, Iteration of rational functions, Springer Verlag , New York, 1991.

8. S. Morosawa, Y. Nishimura, M. Taniguchi, T. Ueda, Holomorphic dynamics, Cambridge University Press, 2000.

Course Title: Linear Algebra

Course Code: MAT.715

Total Hours: 60

L	T	P	Credits
4	0	0	4

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.

Unit/ Hours	Content	Mapping with CLO
UNIT-I 14 Hours	Vector spaces, Subspaces: Definition and Examples, Linear dependence and independence, Basis and dimensions, Coordinates, Linear transformations, Algebra of linear transformations, Isomorphism, Matrix representation of a linear transformation.	**CLO1 CLO2**
UNIT-II 16 Hours	Change of basis, Rank and nullity of a linear transformation. Linear functionals, Dual spaces, Transpose of a linear transformation. Annihilating Polynomials: Characteristic polynomial and minimal polynomial of a linear transformation, Characteristic values and Characteristic vectors of a linear transformation, Cayley Hamilton theorem.	**CLO3**
UNIT-III 16 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.	**CLO4**
UNIT-IV 14 Hours	Inner product spaces. Norms and distances, Orthonormal basis, Orthogonality, Schwarz inequality, The Gram-Schmidt orthogonalization process.Orthogonal and positive definite matrices.	**CLO5 CLO6**

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,* 2nd Edition, Pearson Education (Asia) Pvt. Ltd/ Prentice Hall of India, 2004.
3. V. Bist and V. Sahai, *Linear Algebra,* Narosa, Delhi, 2002.
4. S Lang, Linear Algebra, Undergraduate texts in mathematics, Springer, 1989.

Course Title: Information Theory

Course Code: MAT. 716
Total Hours 60

L	T	P	Credits
4	0	0	4

Learning outcomes:.
The student will be able to:
CLO1: Understand the basics of various information measures.
CLO2: Explain the chain rules for entropy.
CLO3: Learn the basics of asymptotic equipartition properties.
CLO4: Learn the concept of data compression and theory of optimal codes.
CLO5: Understand the concept of channel capacity of public channels.

Unit/ Hours	Content	Mapping with CLO
UNIT-I 14 Hours	**Information Measures**: Entropy, Joint Entropy, Conditional Entropy, Relative Entropy, Mutual Information, Relationship Between Entropy and Mutual Information, Chain Rules for Entropy, Relative Entropy and Mutual Information.	**CLO1 CLO2**
UNIT-II 16 Hours	Asymptotic Equipartition Property (AEP), AEP for Continuous Random Variables, Divergence, Differential Entropy, Relation of Differential Entropy to Discrete Entropy, Properties of Differential Entropy, Relative Entropy, and Mutual Information.	**CLO3**
UNIT-III 16 Hours	Data Compression, Kraft Inequality, Optimal Codes, Bounds on the Optimal Code Length, Kraft Inequality for Uniquely Decodable Codes, Huffman Codes, Some remarks related to Huffman Codes, Optimality of Huffman Codes	**CLO4**
UNIT-IV 14 Hours	Channel Capacity- Examples of Channel Capacity, Symmetric Channels, Properties of Channel Capacity, Preview of the Channel Coding Theorem, Jointly Typical Sequences, Channel Coding Theorem, Zero-Error Codes, Feedback Capacity, Source–Channel Separation Theorem.	**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. Thomas M. Cover, Joy A. Thomas: Elements of Information Theory, 2nd Edition, Wiley, ISBN: 978-0-471-24195-9, 2006.
2. I. Csiszár and J. Körner, Information Theory, Cambridge, 2011.
3. R. Gallager, Information Theory and Reliable Communication, Wiley, 1968.
4. J.M. Wozencraft and I.M. Jacobs, Principles of Communication Engineering,Wiley, 1965.
5. C.E. Shannon, The Mathematical Theory of Communication, University of Illinois Press, 1949.
6. R. Yeung, Information Theory and Network Coding, Springer, 2008.

Course Title: **Algebraic Cryptography**

Course Code: MAT. 717

Total Hours 60

L	T	P	Credits
4	0	0	4

Learning outcomes:.
The student will be able to:
CLO1: Understand the basics of various types of data security goals.
CLO2: Explore about the techniques of steganography.
CLO3: Understand the notion of AES, DES, and one time pad and their applications.
CLO4: Learn the concept linear feedback shift register and hash functions.
CLO5: Understand the concept of Walsh-Hadamard transform and its application in security analysis.

Unit/Hours	Content	Mapping with CLO
UNIT-I 14 Hours	**Data Security:** Various Security Goals: Confidentiality, Integrity, Availability, Authentication, Access Control, Non-Repudiation, Steganography.	**CLO1 CLO2**
UNIT-II 16 Hours	**Public-Key Cryptography:** Cryptanalysis, Public-Key Cryptosystems, Data Encryption Standard (DES), Advanced Encryption Standard (AES), Symmetric Key Cipher, Substitution Cipher, The One Time Pad: Vernam's Cryptosystem, Stream Ciphers, Block Ciphers, S-Boxes	**CLO3**
UNIT-III 16 Hours	**Linear Feedback Shift Registers**: Linear and Nonlinear Feedback Shift Registers, Cryptanalysis and Different kinds of Attacks: Linear Attacks, Differential Attacks, Algebraic Attacks, Perfect Secrecy, Cryptographic Hash Functions, Security of Hash Functions.	**CLO4**

UNIT-IV **14 Hours**	Cryptographic Boolean Functions, Representation of Boolean Functions: Algebraic Normal Form, Trace Representation, Polar Representation, Truth Table Representation, The Discrete Fourier Transform, Balanced Boolean Functions, Affine Functions, Quadratic Boolean Functions, Walsh-Hadamard Transform of Affine and Quadratic Boolean 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. Stallings W., Cryptography and Network Security, Pearson Education India, 2008
2. Hoffstein J., Pipher J., Silverman J.H., An Introduction to Mathematical Cryptography, Springer, 2011.
3. Stinson D.R., Cryptography: Theory and Practice, Chapman & Hall/CRC, Taylor & Francis, 2006.
4. Burton D.M., Elementary Number Theory, Tata McGraw Hill Publication, 2006.
5. Menezes A., Van Oorschot P., and Vanstone S., Handbook of Applied Cryptography, CRC Press, 1996.
6. Schneier B., Applied Cryptography, Publisher: John Willley and Sons Inc., 2008.
7. Elizabeth D. and Denning R., Cryptography and Data Security, Addison Wesley Publishing Company, 1982
8. Delfs H. and Knebl H., Introduction to Cryptography: Principles and Applications, Springer, 2007.
9. Goldreich O., Foundations of Cryptography, Cambridge University Press Publication, 2004.

Course Name: Stochastic Differential Equations
Course Code: MAT.718
Total Hours: 60

L	T	P	Credits
4	0	0	4

Learning outcomes:

The students will be able to

CLO1: Explain Stochastic Processes.
CL02: learn and solve the stochastic differential equations (SDE).
CL03: find the connections between connection between SDE and partial differential equations (PDE)
CL04: formulate the SDE models.

Units/ Hours	Contents	Mapping with CLO

UNIT-I 15 Hours	A review of the necessary prerequisites in probability theory, including an introduction to stochastic processes in discrete and continuous time. Brownian motion (the Wiener process), the Ito integral and the Ito calculus,	**CLO1**
UNIT-II 15 Hours	Introduction to stochastic differential equations (SDE) and solving certain types of SDE analytically with Ito calculus. Furthermore the general existence and uniqueness theory for SDE, numerical methods for simulating solutions to SDEs.	**CLO2**
UNIT-III 15 Hours	The connection between SDE and partial differential equations (PDE) :(e.g. Fokker-Plancks's equation) solutions of PDEs in separate points by using simulations of SDEs.	**CLO3**
UNIT-IV 15 Hours	SDE models are formulated and fitted to given data, and are studied in some examples of applications.	**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. Karatzas and S. E. Shreve, Brownian motion and stochastic calculus, 2nd ed., Graduate Texts in Mathematics, vol. 113, Springer-Verlag, New York, 1991
2. B. Øksendal, Stochastic differential equations, 6th ed., University text, Springer-Verlag, Berlin, 2003.
3. A. Friedman, Stochastic differential equations and applications, Dover Publications Inc., Mineola, NY, 2006.
4. Allen E., Modeling with Itô stochastic differential equations Springer, 2007

Course Title: Fluid Dynamics
Course Code: MAT.719
Total Hours: 60

L	T	P	Credits
4	0	0	4

Learning outcomes:

The students will be able to

CLO1: Review of Basic Concepts of Fluid Dynamics.

CL02: learn equations of motion of fluid.

CL03: Will be able to solve many problems related to fluid dynamics.

CL04: learn basics of Navier-Stokes equations. Students can model basic and some advanced fluid flow problems and solve them.

Units/ Hours	Contents	Mapping with CLO
UNIT-I 15 Hours	Review of gradient, divergence and curl. Elementary idea of tensors. Velocity of fluid, Streamlines and path lines, Steady and unsteady flows, Velocity potential, Vorticity vector, Conservation of mass, Equation of continuity.	**CL01**
UNIT-II 15 Hours	Equations of motion of a fluid, Pressure at a point in fluid at rest, Pressure at a point in a moving fluid, Euler's equation of motion, Bernoulli's equation. Singularities of flow, Source, Sink, Doublets, Rectilinear vortices.	**CL02**
UNIT-III 15 Hours	Complex variable method for two-dimensional problems, Complex potentials for various singularities, Circle theorem, Blasius theorem, Theory of images and its applications to various singularities. Three dimensional flows, Irrotational motion, Weiss's theorem and its applications.	**CL03**
UNIT-IV 15 Hours	Viscous flow, Vorticity dynamics, Vorticity equation, Reynolds number, Stress and strain analysis, Navier-Stokes equation, Boundary layer Equations.	**CL04**

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 K Batchelor, An Introduction to fluid dynamics, Cambridge University Press , A seminal book on fluid dynamics
2. F M White, Fluid Mechanics, Tata McGraw Hill, One will find many solved and unsolved problems.
3. F. Chorlton, A text book of fluid dynamics, Von Nostrand Reinhold/CBS , Very good book for beginners.
4. L. M. Milne Thomson, Theoretical Hydrodynamics, Macmillan and Co, A good book on mathematical fluid dynamics.