

## M.Tech. Program from the Dept. of Mathematics

### M. Tech. in Mathematics and Computing

Program Learning Objectives:	Program Learning Outcomes:
<b>Program Goal 1:</b> To train students in both Mathematics and Computer Science to be able to address the increasing demand in both the areas.	<b>Program Learning Outcome 1:</b> With a mix of Mathematics and Computer Science courses, students explore the deep connection between computing and fundamental mathematics.
<b>Program Goal 2:</b> To pursue a bright career in industry.	<b>Program Learning Outcome 2:</b> Students become experts in different fields in industry due to their strong fundamental in Mathematics and Computer Science.
<b>Program Goal 3:</b> To pursue a successful career in academia.	<b>Program Learning Outcome 3:</b> Courses from Mathematics and Computer Science introduce the flavor of research and motivate the students to build a successful career in academia.
<b>Program Goal 4:</b> To prepare basics as strong foundation to achieve goals in higher academic degrees.	<b>Program Learning Outcome 4a:</b> Foundation is made strong with systematics training in pure and applied mathematics which helps in higher degrees. <b>Program Learning Outcome 4b:</b> Computer science courses provide a platform to further explore the programs in the contemporary areas of computer science

Sl. No.	Subject Code	SEMESTER I	L	T	P	C
1.	HS5111	Technical Writing and Soft Skills	1	2	2	4
2.	MC5101	Design and Analysis of Algorithms	3	1	0	4
3.	MC5102	Probability and Statistics	2	0	2	3
4.	MC5103	Computing Lab-1	0	1	2	2
5.	XX51PQ/ XX61PQ	DE-I	3	0	0	3
6.	XX51PQ/ XX61PQ	DE-II	3	0	0	3
7.	XX51PQ/ XX61PQ	DE-III	3	0	0	3
8.	XX61PQ	IDE	3	0	0	3
	<b>TOTAL</b>		<b>18</b>	<b>4</b>	<b>6</b>	<b>25</b>

#### Important Note:

1. Department electives of Computer Science offered to M. Tech. (CSE) students may be chosen as department elective by M. Tech. (M&C) students.

**2. IDE (Inter Disciplinary electives)** in the curriculum aims to create multitasking professionals/ scientists with learning opportunities for students across disciplines/apptitude of their choice by opting level (5 or 6) electives, as appropriate, listed in the approved curriculum.

Sl. No.	Subject Code	SEMESTER II	L	T	P	C
1.	MC5201	Advanced Artificial Intelligence	3	0	0	3
2.	MC5202	Numerical Linear Algebra and Optimization Techniques	2	0	2	3
3.	MC5203	Advance Artificial Intelligence Lab	0	1	2	2
4.	XX52PQ/ XX62PQ	DE-IV	3	0	0	3
5.	XX52PQ/ XX62PQ	DE-V	3	0	0	3
6.	XX52PQ/ XX62PQ	DE-VI	3	0	0	3
7.	RM6201	Research Methodology	3	1	0	4
8.	IK6201	Indian Knowledge System	3	0	0	3
		<b>TOTAL</b>	<b>20</b>	<b>2</b>	<b>4</b>	<b>24</b>

**Imp. Note:** Department electives of Computer Science offered to M. Tech. (CSE) students may be chosen as department elective by M. Tech. (M&C) students.

Sl. No.	Subject Code	SEMESTER III	L	T	P	C
1.	MC6198	Summer Internship Evaluation / Mini Project*	0	0	12	3
2.	MC6199	Project I**	0	0	30	15
		<b>TOTAL</b>	<b>0</b>	<b>0</b>	<b>42</b>	<b>18</b>

**\*Note: Summer Internship (Credit based)**

(i) Summer internship (\*) period of at least 60 days' (8 weeks) duration begins in the intervening summer vacation between Semester II and III. It may be pursued in industry / R&D / Academic Institutions including IIT Patna. The evaluation would comprise **combined grading based on host supervisor evaluation, project internship report after plagiarism check and seminar presentation at the Department (DAPC to coordinate)** with equal weightage of each of the three components stated herein.

(ii) Further, on return from 60 days internship, students will be evaluated for internship work through combined grading based on host supervisor evaluation, project internship report after plagiarism check, and presentation evaluation by the parent department with equal weightage of each component.

**\*\*Note: M. Tech. Project outside the Institute**

In the IX<sup>th</sup> Semester, students can opt for a semester long M. Tech. project subject to confirmation from an Institution of repute for research project, on the assigned topic at any external Institution (Industry / R&D lab / Academic Institutions) based on recommendation of the DAPC provided:

(i.) The project topic is well defined in objective, methodology and expected outcome through an abstract and statement of the student pertaining to expertise with the proposed supervisor of the host institution and consent of the faculty member from the concerned department at IIT Patna as joint supervisor.

(ii.) The consent of both the supervisors (external and institutional) on project topic is obtained a priori and forwarded to the academic section through DAPC for approval by the competent authority for office record in the personal file of the candidate.

(iii.) Confidentiality and Non Disclosure Agreement (NDA) between the two organizations with clarity on intellectual property rights (IPR) must be executed prior to initiating the semester long project assignment and committing the same to external organization and vice versa.

(iv.) The evaluation in each semester at Institute would be mandatory and the report from Industry Supervisor will be given due weightage as defined in the Academic Regulation. Further, the final assessment of the project work on completion will be done with equal weightage for assessment of the host and Institute supervisors, project report after **plagiarism check**. The award of grade would comprise **combined assessment based on host supervisor evaluation, project report quality and seminar presentation at the Department (DAPC to coordinate)** with equal weightage of each of the components stated herein.

(v.) In case of poor progress of work and / or no contribution from external supervisor, the student need to revert back to the Institute essentially to fulfill the completion of M. Tech. project as envisaged at the time of project allotment. However, the recommendation of DAPC based on progress report and presentation would be mandatory for a final decision by the competent authority.

Sl. No.	Subject Code	SEMESTER IV	L	T	P	C
1.	MC6299	Project II	0	0	42	21
		<b>TOTAL</b>	<b>0</b>	<b>0</b>	<b>42</b>	<b>21</b>

**Total Credit        -        88**

### **ELECTIVE GROUPS**

Sl. No.	Subject Code	Department Elective - I	L	T	P	C
1.	MA5104	Cryptography and Network Security	3	0	0	3
2.	MA6101	Advanced Graph Theory	3	0	0	3
3.	MA6102	Introduction to Algebraic D-modules	3	0	0	3
4.	MA6103	Nonlinear Optimization	3	0	0	3
5.	CS6101	Advanced Blockchain Technology	3	0	0	3
6.	CS6102	Advanced Cyber Security	3	0	0	3
7.	CS6103	Advanced Pattern Recognition	3	0	0	3
8.	CS6104	Formal Methods in Program Analysis and Verification	3	0	0	3
9.	CS6105	Federated Learning	3	0	0	3

Sl. No.	Subject Code	Department Elective - II	L	T	P	C
1.	MA5104 MA5105	Fundamentals of Block Chain	3	0	0	3
2.	MA5105 MA5106	Mathematical Finance	3	0	0	3
3.	MA6104	Generative AI	2	0	2	3
4.	MA6105	Rings and Modules	3	0	0	3
5.	CS6106	Advanced Cloud Computing	3	0	0	3
6.	CS6107	Advanced Edge Computing	3	0	0	3
7.	CS6108	Advanced Computational Data Analysis	3	0	0	3
8.	CS6109	Reinforcement Learning	3	0	0	3
9.	CS6110	Advanced Graph Machine Learning	3	0	0	3
10.	CS6111	Advanced Time Series Analysis	3	0	0	3

Sl. No.	Subject Code	Department Elective - III	L	T	P	C
1.	MA6106	Large Language Models (LLMs)	2	0	2	3
2.	MA6107	Number Theory	3	0	0	3
3.	MA6108	Stochastic Calculus for Finance	3	0	0	3

Sl. No.	Subject Code	Department Elective - IV	L	T	P	C
1.	MA5201	Portfolio Theory and Risk Management	3	0	0	3
2.	MA6202	Introduction to Biomathematics	3	0	0	3
3.	MA6203	Introduction to Homological Algebra	3	0	0	3
4.	MA6204	Noncommutative Algebra	3	0	0	3
5.	MA6205	Sobolev Spaces	3	0	0	3
6.	MA6206	Wavelet Transform	3	0	0	3
7.	CS6201	Artificial Internet of Things	3	0	0	3
8.	CS6202	Game Theory	3	0	0	3
9.	CS6203	Text Mining & Analytics	3	0	0	3

Sl. No.	Subject Code	Department Elective - V	L	T	P	C
1.	MA6207	Differential Manifolds	3	0	0	3
2.	MA6208	Graph Algorithms	3	0	0	3
3.	MA6209	Numerical solutions of PDEs	2	0	2	3
4.	MA6210	Statistical Inference	3	0	0	3
5.	MA6217	Database and Data Mining	2	0	2	3
6.	CS6204	Knowledge Distillation	3	0	0	3
7.	CS6205	Physics of Neural Network	3	0	0	3
8.	CS6206	Selected Topics in Wireless Networks	3	0	0	3
9.	CS6207	Advanced Big Data Analytics	3	0	0	3

Sl. No.	Subject Code	Department Elective - VI	L	T	P	C
1.	MA5203	Discrete Mathematics	3	0	0	3
2.	MA6211	Advanced Complex Analysis	3	0	0	3
3.	MA6212	Algebraic Coding Theory	3	0	0	3
4.	MA6213	Finite Element Analysis	3	0	0	3

5.	MA6214	Introduction to Algebraic Geometry	3	0	0	3
6.	MA6215	Operators on Hilbert Spaces	3	0	0	3
7.	MA6216	Riemannian Geometry	3	0	0	3
8.	CS6208	Quantum Machine Learning	3	0	0	3
9.	CS6209	Meta Learning	3	0	0	3
10.	CS6210	Selective Topics in Generative AI	3	0	0	3

**Interdisciplinary Elective (IDE) Course for M. Tech. (Available to students other than Math)**

<b>Sl. No.</b>	<b>Subject Code</b>	<b>IDE</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
1.	MA6109	Mathematical Modeling	3	0	0	3

<b>Sl. No.</b>	<b>Subject Code</b>	<b>SEMESTER I</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
1.	HS5111	Technical Writing and Soft Skills	1	2	2	4
2.	MC5101	Design and Analysis of Algorithms	3	1	0	4
3.	MC5102	Probability and Statistics	2	0	2	3
4.	MC5103	Computing Lab-1	0	1	2	2
5.	XX51PQ/ XX61PQ	DE-I	3	0	0	3
6.	XX51PQ/ XX61PQ	DE-II	3	0	0	3
7.	XX51PQ/ XX61PQ	DE-III	3	0	0	3
8.	XX61PQ	IDE	3	0	0	3
	<b>TOTAL</b>		<b>18</b>	<b>4</b>	<b>6</b>	<b>25</b>

Course number	MC5101
Course Credit	3-1-0-4
Course Title	<b>Design and Analysis of Algorithms</b>
Learning Mode	offline
Learning Objectives	The objective of this course is to equip students with a solid understanding of data structures and algorithms, enabling them to design, analyze, and implement efficient algorithms to solve complex computational problems. The course covers fundamental topics such as data structures, complexity analysis, sorting and searching techniques, problem-solving strategies, graph algorithms. By the end of the course, students will have developed the skills to critically analyze algorithm efficiency and apply advanced algorithms in practical scenarios.
Course Description	This course will provide understanding of advanced methods to solve problems on computers. It will also provide an overview to analyze those theoretically.
Course Outline	Fibonacci heap, unionfind, splay trees. Amortized complexity analysis Randomized algorithms Reducibility between problems and NP-completeness: discussion of different NP-complete problems like satisfiability, clique, vertex cover, independent set, Hamiltonian cycle, TSP, knapsack, set cover, bin packing, etc. Backtracking, branch and bound Approximation algorithms: Constant ratio approximation algorithms. Application areas(i)Geometric algorithms: convex hulls, nearest neighbor, Voronoi diagram, etc.(ii)Algebraic and number-theoretic algorithms: FFT, primality testing, etc.(iii)Graph algorithms: network flows, matching, etc.(iv)Optimization techniques: linear programming
Learning Outcome	By the end of this course, students will be able to solve problems that are computationally intractable
Assessment Method	Internal(Quiz/Assignment/Project), Mid-Term, End-Term

### Suggested Reading:

- Mark Allen Weiss, "Data Structures and Algorithms in C++", Addison Wesley, 2003.
- Adam Drozdek, "Data Structures and Algorithms in C++", Brooks and Cole, 2001.
- Aho, Hopcroft and Ullmann, "Data structures and Algorithm", Addison Welsey, 1984.
- Introduction to Algorithms Book by Charles E. Leiserson, Clifford Stein, Ronald Rivest, and Thomas H. Cormen
- Sanjoy Dasgupta, Christos H. Papadimitriou and Umesh V. Vazirani, Algorithms, Tata McGraw-Hill, 2008.
- Steven Skiena, The Algorithm Design Manual, Springer
- Jon Kleinberg and Éva Tardos, Algorithm Design, Pearson, 2005.
- Robert Sedgewick and Kevin Wayne, Algorithms, fourth edition, Addison Wesley, 2011.
- Udi Manber, Algorithms – A Creative Approach, Addison-Wesley, Reading, MA, 1989.
- Tim Roughgarden, Algorithms Illuminated

Course Number	MC5102 (Core)
Course Credit	3-0-2-4
Course Title	Probability and Statistics
Learning Mode	Lectures and Labs
Learning Objectives	To understand the basic concepts in Probability Theory and Statistics through practical examples.
Course Description	The course is divided into two parts: In first part, basic concepts of probability theory are introduced. In the second part, different problems in classical statistics are discussed.
Course Outline	<p>Conditional probability, Bayes' rule, Total probability law, Independence of events. Random variables (discrete and continuous), probability mass functions, probability density functions, Expectation, variance, moments, cumulative distribution functions, Function of random variables, Multiple random variables, joint and marginal, conditioning and independence, Markov and Chebyshev inequalities, Different notions of convergence. Weak law of large number, Central limit theorem.</p> <p>Estimation: Properties, Unbiased Estimator, Minimum Variance Unbiased Estimator, Rao-Cramer Inequality and its attainment, Maximum Likelihood Estimator and its invariance property, Efficiency, Mean Square Error.</p> <p>Confidence Interval: Coverage Probability, Confidence level, Sample size determination.</p> <p>Testing of Hypotheses: Null and Alternative Hypotheses, Test Statistic, Error Probabilities, Power Function, Level of Significance, Neyman-Pearson Lemma.</p>
Learning Outcome	Students will become familiar with principal concepts probability theory and statistics. This helps them to handle, mathematically, various practical problems arising in uncertain situations.
Assessment Method	Quiz / Assignment / MSE / ESE

**Text Books:**

1. Ross, S.M.(2008) Introduction to Probability Models, Ninth edition, Academic Press.
2. Statistical Inference (2007), G. Casella and R.L. Berger, Duxbury Advanced Series.

**Reference Book:**

1. An Introduction to Probability and Statistics, V.K. Rohatgi and A.K.Md. Ehsanes Saleh, John Wiley, 2nd Ed, 2009.



Course Number	MC5103
Course Credit	0-1-2-2
Course Title	<b>Computing Lab-1</b>
Learning Mode	Offline
Learning Objective	The course aims to develop students' analytical and practical skills in designing efficient algorithms and understanding the complexities of operating systems. Students will learn to analyze the efficiency of algorithms, understand various algorithmic strategies, and implement them to solve complex problems. In the Operating Systems segment, students will explore the core concepts, including process management, memory management, file systems, and concurrency. By the end of the course, students will be proficient in both designing algorithms and managing operating system resources, preparing them for advanced studies and professional careers in computer science.
Course Description	This lab course is structured to provide an in-depth understanding of both algorithm design and operating system concepts. The Design and Analysis of Algorithms section covers fundamental topics such as sorting, searching, dynamic programming, greedy algorithms, and graph algorithms. Students will learn to critically evaluate the efficiency and applicability of different algorithms. The Operating Systems section delves into process scheduling, memory management techniques, file systems, and synchronization mechanisms. Through a series of hands-on labs and projects, students will apply theoretical knowledge to practical scenarios, reinforcing their understanding and problem-solving abilities.
Course Outline	The course begins with an introduction to basic algorithmic concepts and techniques, progressing through various algorithm design paradigms such as divide-and-conquer, dynamic programming, and greedy methods. Concurrently, students will explore the architecture and functionalities of operating systems, starting with process management and memory management, then advancing to file systems, I/O systems, and concurrency control. The course will include practical lab sessions where students will implement and test algorithms, as well as design and manage operating system components. The course culminates in a comprehensive project that integrates both algorithm design and operating system principles to solve complex computing problems.
Learning Outcome	Upon completing this course, students will have a solid grasp of both algorithm design and analysis, as well as operating system functionalities. They will be able to design, analyze, and implement efficient algorithms to address computational problems. Additionally, students will gain practical experience in managing operating system resources, including process scheduling, memory management, and file systems. This dual expertise will equip students with the skills necessary for tackling advanced topics in computer science and pursuing careers in software development, system administration, and research.
Assessment Method	Internal(Quiz/Assignment/Project), Mid-Term, End-Term

**Suggested readings:**

- "Introduction to Algorithms" by Thomas H. Cormen, Charles E. Leiserson, Ronald L. Rivest, and Clifford Stein, 4th Edition
- "Algorithms" by Robert Sedgewick and Kevin Wayne, 4th Edition
- "Operating System Concepts" by Abraham Silberschatz, Peter B. Galvin, and Greg Gagne, 10th Edition
- "Modern Operating Systems" by Andrew S. Tanenbaum and Herbert Bos, 4th Edition
- "The Algorithm Design Manual" by Steven S. Skiena, 3rd Edition

<b>Sl. No.</b>	<b>Subject Code</b>	<b>Department Elective - I</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
1.	MA5104	Cryptography and Network Security	3	0	0	3
2.	MA6101	Advanced Graph Theory	3	0	0	3
3.	MA6102	Introduction to Algebraic D-modules	3	0	0	3
4.	MA6103	Nonlinear Optimization	3	0	0	3
5.	CS6101	Advanced Blockchain Technology	3	0	0	3
6.	CS6102	Advanced Cyber Security	3	0	0	3
7.	CS6103	Advanced Pattern Recognition	3	0	0	3
8.	CS6104	Formal Methods in Program Analysis and Verification	3	0	0	3
9.	CS6105	Federated Learning	3	0	0	3

<b>Course Number</b>	MA5104 (DE)
<b>Course Credit</b>	3-0-0-3
<b>Course Title</b>	Cryptography and Network Security
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	The objective of the course is to present an introduction to Cryptography, with an emphasis on how to protect information security from unauthorized users and is to understand the basics of Network vulnerability and Security Protection.
<b>Course Description</b>	The aim of this course is to introduce the student to the areas of cryptography and cryptanalysis. This course develops a basic understanding of the algorithms used to protect users online and to understand some of the design choices behind these algorithms.
<b>Course Content</b>	Security goals and attacks, Cryptography and cryptanalysis basics, Mathematics behind cryptography, Traditional and modern symmetric-key ciphers, DES, AES, Asymmetric-key ciphers, One-way function, Trapdoor one-way function, Chinese remainder theorem, RSA cryptosystem, Elgamal Cryptosystem, Diffie-Hellman key exchange algorithm, Elliptic curve cryptography, Cryptographic hash function, Message authentication, PKI, Digital signature, RSA digital signature, Security at the Network Layer: IPSec and IKE, Security at the Transport Layer: SSL and TLS, Security at the Application Layer: PGP and S/MIME
<b>Learning Outcome</b>	Students will be familiar with the significance of information security in the digital era. Also, they can identify various threats and vulnerabilities in networking.
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### **Text Books:**

1. Cryptography and Network Security by Behrouz A. Forouzan and Debdeep Mukhopadhyay, Second edition, Tata McGraw Hill, 2011.
2. Cryptography and Network Security Principles and practice by W. Stallings, 5/e, Pearson Education Asia, 2012.

#### **Reference Books:**

1. Cryptography: Theory and Practice by Stinson. D., third edition, Chapman & Hall/CRC, 2010.
2. Elementary Number Theory with applications by Thomas Koshy, Elsevier India, 2005.
3. Research papers

<b>Course Number</b>	MA6101 (DE)
<b>Course Credit (L-T-P-C)</b>	3-0-0-3
<b>Course Title</b>	Advanced Graph theory
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	To learn various notions in basic and advanced graph theory and their applications.
<b>Course Description</b>	This course is meant to introduce various notions in graph theory and their application.
<b>Course Outline</b>	Basic definitions in graph theory, trees, connectivity, spanning trees, Eulerian and Hamiltonian graphs, matching in graphs, planar graphs, graph Coloring, Ramsay Theory: Applications, bounds on Ramsay number, Ramsay theory for integers, Graph Ramsay numbers. Extremal graph theory: Minors, Hadwiger's conjecture, Szemerédi's regularity lemma and its application Random graphs: Introduction, probabilistic method, threshold function.
<b>Learning Outcome</b>	Students will be accustomed to the basic graph and advanced topics in graph theory. They will be able to model different real-life problems using graph theory and also this course gives them basic foundation to do research in graph theory
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### **Text Books:**

1. Algorithm Design By Jon Kleinberg, Éva Tardos, Pearson Education
2. The Design of Approximation Algorithms By David P. Williamson, David B. Shmoys, Cambridge University Press
3. Probability and Computing: Randomization and Probabilistic Techniques in Algorithms and Data Analysis By Michael Mitzenmacher, Eli Upfal , Cambridge University Press

#### **Reference Books:**

1. Design and Analysis of Algorithms: A Contemporary Perspective By Sandeep Sen and Amit Kumar, Cambridge University Press
2. Algorithms By Sanjoy Dasgupta, Christos H. Papadimitriou, Umesh Virkumar Vazirani, McGraw-Hill Higher Education

<b>Course Number</b>	MA6102 (DE)
<b>Course Credit (L-T-P-C)</b>	3-0-0-3
<b>Course Title</b>	Introduction to algebraic D-modules
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	The goal of this course is to provide a fundamental knowledge of Weyl algebra and its properties. It is intended that the students become familiar with the main basic techniques and results of this area and become ready for research projects.
<b>Course Description</b>	This course will cover the theory of Weyl algebras, ring of differential operators and Jacobian conjecture. Further, Graded rings, filtered rings, Hilbert polynomial and Bernstein inequality will be discussed.
<b>Course Content</b>	(Review of Rings, Ideals, Homomorphism, Isomorphism, Vector spaces, Bases, Dimensions, Linear operators, Algebras, Subalgebras.) Derivations on rings, Weyl algebras, Canonical forms, Generators and Relations, Degree of an Operator, Ideal structure, Positive characteristic, Ring of differential Operators, Jacobian Conjecture, Polynomial maps, Modules over the Weyl Algebra, D-module of an equation, Direct limit of modules. Graded rings, Filtered rings, Graded algebra, Filtered modules, Induced filtration, Noetherian modules, Good filtration, Hilbert polynomial, dimension and multiplicity, Bernstein inequality.
<b>Learning Outcome</b>	Upon successful completion of this course students should: <ol style="list-style-type: none"> <li>1. recognise technical terms and appreciate some of the uses of Weyl algebra.</li> <li>2. Demonstrate knowledge of the advanced language of algebraic D-modules and thus get access to the wide literature that uses it.</li> <li>3. Use the algebraic technique of D-modules to solve the complicated analytic problems concerning invariant distributions.</li> </ol>
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### **Text Books:**

1. S. C. Coutinho, A primer of algebraic D-modules, London Mathematical Society, Student Text 33, 1995.
2. J. Bernstein, Algebraic Theory of D-modules (Lecture notes), 2016.
3. A. Braverman and T. Chmutova, Lectures on algebraic D-modules, 2016.

#### **Reference Books:**

1. L. Rowen, Graduate algebra: noncommutative view, Graduate Studies in Mathematics, 91.
2. A. Borel, J. Coates and S. Helgason, Algebraic D-Modules (Perspectives in Mathematics), Academic Press 1987.

<b>Course Number</b>	MA6103 (DE)
<b>Course Credit (L-T-P-C)</b>	3-0-0-3
<b>Course Title</b>	Nonlinear Optimization
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	The objective of the course is to train students about the modeling and solution of nonlinear programming problems and various algorithms to solve these problems. Moreover, several optimality conditions and duality models are also discussed.
<b>Course Description</b>	Nonlinear Optimization, as a basic subject for Master and PhD students, provides the basic knowledge of various types of optimality conditions for constrained and unconstrained nonlinear programming problems and different algorithms to solve these problems. Moreover, generalized convexity notions and duality models will be described. with its applications in several problems arising in economics, science and engineering.
<b>Course Content</b>	<p>Convex Sets and Its Properties, Support and Separation Theorems, Convex Cones and Polar Cones, Polyhedral Cones, Cone of Tangents, Cone of Attainable Directions, Cone of Feasible Directions</p> <p>Convex Functions: Definitions and Preliminary Results, Continuity and Directional Differentiability of Convex Functions, Differentiable Convex Functions and Properties</p> <p>Quasiconvex Function, Pseudoconvex Functions, Characterization and Properties</p> <p>Optimality Conditions for Unconstrained Minimization and Constrained Minimization Problems, Lagrange's Multiplier Method, Inequality Constrained Problems, Constraint Qualifications, Saddle Point Optimality Criteria, KKT conditions, Mond Weir and Wolfe Duality.</p> <p>Unimodal functions, Fibonacci search, Line search methods, Convergence of Generic Line Search Methods, Method of Steepest Descent, Conjugate gradient methods, Fletcher Reeves Method, Quasi-Newton Method, BFGS Method, Convergence Analysis for Quadratic functions; Interior point methods for inequality constrained optimization, Merit functions for Constrained Minimization, Logarithmic Barrier Function for Inequality Constraints, A basic Barrier-Function Algorithm.</p> <p>Practice with software such as Python/MATLAB</p>
<b>Learning Outcome</b>	<p>On successful completion of the course, students should be able to:</p> <ol style="list-style-type: none"> <li>1. Understand the terminology and basic concepts of various kinds of nonlinear programming problems</li> <li>2. model several dual models related to nonlinear programming problems</li> <li>3. Develop the understanding of about different solution methods and algorithms to solve nonlinear Programming problems.</li> <li>4. Apply and differentiate the need for and importance of various algorithms to solve nonlinear programming problems</li> <li>5. Model and solve real-life problems using optimization algorithms</li> </ol>
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### **Text Books:**

1. M. S. Bazaraa, J. J. Jarvis and H. D. Sherali, E.K.P. Chong, S.H. Zak, An Introduction to Optimization, 3rd Edition, John Wiley, 2008.
2. J. Nocedal and S. Write, Numerical Optimization, Springer Science, 1999
3. E.K.P. Chong and S.H. Zak, An Introduction to Optimization, 3rd Edition, John Wiley, 2008.

#### **Reference Books:**

1. Stephan Boyd and L. Vandenberghe, Convex Optimization, Cambridge University Press, 2009.
2. O.L. Mangasarian, Nonlinear Programming, SIAM Classics in Applied Mathematics, 1969

Sl. No.	Subject Code	Department Elective - II	L	T	P	C
1.	MA5104 MA5105	Fundamentals of Block Chain	3	0	0	3
2.	MA5105 MA5106	Mathematical Finance	3	0	0	3
3.	MA6104	Generative AI	2	0	2	3
4.	MA6105	Rings and Modules	3	0	0	3
5.	CS6106	Advanced Cloud Computing	3	0	0	3
6.	CS6107	Advanced Edge Computing	3	0	0	3
7.	CS6108	Advanced Computational Data Analysis	3	0	0	3
8.	CS6109	Reinforcement Learning	3	0	0	3
9.	CS6110	Advanced Graph Machine Learning	3	0	0	3
10.	CS6111	Advanced Time Series Analysis	3	0	0	3



<b>Course Number</b>	MA5105 (DE)
<b>Course Credit</b>	3-0-0-3
<b>Course Title</b>	Fundamentals of Block Chain
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	To give students the understanding of emerging abstract models for Blockchain Technology and to familiarize with the functional/operational aspects of cryptocurrency eco-system.
<b>Course Description</b>	This course will be on the fundamentals of Blockchain and Blockchain Technology. After covering fundamentals, we will look at some applied uses and criticisms. The best-known example of Blockchain Technology in wide use today is as the storage and transaction mechanism for the cryptocurrency Bitcoin.
<b>Course Content</b>	Concepts of cryptocurrency and Blockchain, Consensus Algorithms-Security of Blockchain, Blockchain Programs and Network, Concept of Blockchain parameters, Double-Spending Problem, Public Key Cryptosystem, Cryptographic Hash Functions, Digital Signatures, Bitcoin Cryptocurrency, Transactions, Mining, Consensus Mechanisms and Validation, Proof of Work (PoW), Introduction of Bitcoin Program, Ethereum Cryptocurrency, Ethereum vs. Bitcoin, Transactions, Ethereum Blocks, Proof of Stake (PoS), Security issues in Blockchain, Anonymity, Sybil Attacks, Selfish Mining, 51/49 ratio Attacks, Introduction to Smart Contracts, Framework of smart contract, Life cycle of smart contract, Challenges of Smart Contract, Case Studies as Blockchain technology based Applications
<b>Learning Outcome</b>	Students will be familiar with blockchain and cryptocurrency concepts. Also, they can design and demonstrate end-to-end decentralized applications.
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### **Text Books:**

1. A. Narayanan, J. Bonneau, E. Felten, A. Miller, and S Goldfeder, "Bitcoin and Cryptocurrency Technologies", Princeton University Press, 2016
2. Xiwei Xu, I. Weber, M. Staples, "Architecture for Blockchain Applications", Springer, 2018.

#### **Reference Books:**

1. M. Swan, "Blockchain: Blueprint for a New Economy", O'Reilly, 2015
2. Daniel Drescher, "Blockchain Basics", Apress.
3. Lecture Note of Prof. S. Vijayakumaran (IIT Bombay), "An Introduction to Bitcoin"
4. Lecture Note of Prof. S. Shukla (IIT Kanpur), "Introduction to Blockchain Technology and Applications"
5. Research papers

<b>Course Number</b>	MA5106 (DE)
<b>Course Credit (L-T-P-C)</b>	3-0-0-3
<b>Course Title</b>	Mathematical Finance
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	The main objective of the course is to introduce the students to the broader area of mathematical finance from a theoretical as well as computational perspective.
<b>Course Description</b>	Mathematical finance, as an interdisciplinary subject, which encompasses topics from financial engineering, mathematics and computational techniques.
<b>Course Content</b>	Financial markets and instruments, risk-free and risky assets; Interest rates, present and future values of cash flows, term structure of interest rates, spot rate, forward rate; Bonds, bond pricing, yields, duration, term structure of interest rates; Asset pricing models, no-arbitrage principle; Cox-Ross-Rubinstein binomial model, geometric Brownian motion model; Financial derivatives, Forward and futures contracts and their pricing, hedging strategies using futures, interest rate and index futures; Swaps and its valuation, interest rate swaps, currency swaps; Options, general properties of options, trading strategies involving options; Discrete time pricing of European and American derivative securities by replication; Continuous time pricing of European and American derivative securities by risk-neutral valuation; Finite difference approach to pricing European options and American options, free-boundary problem; Monte-Carlo simulation under risk neutral measure for computing financial derivative prices.
<b>Learning Outcome</b>	On successful completion of the course, students should be able to: 1. Understand the fundamentals of quantitative finance. 2. Grasp the concept of time value of money and interest rates. 3. Comprehend ideas of pricing through the application of basic apply mathematical concepts. 4. Implementation of the theoretical topics through computational implementation expected in finance industry.
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### **Text Books:**

1. M. Capinski and T. Zastawniak, Mathematics for Finance: An Introduction to Financial Engineering, 2nd Edition, Springer, 2010.
2. D. Higham, Introduction to Financial Option Valuation: Mathematics, Stochastic and Computation, Cambridge University Press, 2004.

#### **Reference Books:**

1. J.C. Hull, Options, Futures and Other Derivatives, 10th Edition, Pearson, 2018.
2. J. Cvitanic and F. Zapatero, Introduction to the Economics and Mathematics of Financial Markets, Prentice-Hall of India, 2007.

<b>Course Number</b>	MA6104 (DE)
<b>Course Credit (L-T-P-C)</b>	2-0-2-3
<b>Course Title</b>	Generative AI
<b>Learning Mode</b>	Lectures and Labs
<b>Learning Objectives</b>	1. Master various generative models including Autoencoders, GANs, Transformers, and Diffusion models for creative AI applications. 2. Understand advanced concepts in Generative AI such as graph neural networks, diffusion models, and the latest architectures to address real-world challenges.
<b>Course Description</b>	The basic knowledge of deep learning is desirable for this course. This course will explore cutting-edge techniques in Generative AI, covering Autoencoders, GANs, Transformers, Diffusion models, and applications in graph data, alongside the latest advancements in the field.
<b>Course Outline</b>	Introduction to Generative AI: Autoencoder (AE), Variational AE, GAN, Types of GANs - Deep Convolutional GAN (DCGAN), Conditional GAN (cGAN), Wasserstein GAN (WGAN), Stacked GAN (StackGAN), Attention GAN, Picture to Picture GAN (Pix2Pix), Cyclic GAN. Transformer Networks: Drawbacks of Recurrent Neural Networks, Self Attention, Transformers, Bidirectional Encoder Representation from Transformer (BERT), Generative pre-trained Transformer (GPT). Diffusion models: Categories (DDPM, NCSN, SDE) of diffusion Model, Application of diffusion model in computer vision and medical imaging. Generative AI for Graph: Basics of Graph Convolutional Neural Network (GCN), Graph Embeddings, Spectral and Spatial GCNs, Graph Autoencoders, GraphGAN, Graph Diffusion Model. Some popular Architectures/concepts in Generative AI: Stable Diffusion, CLIP, DALL·E, ChatGPT, Self-supervised Learning, Knowledge Distillation, Model compression/Network Pruning, Explainable AI, etc.
<b>Learning Outcome</b>	1. Acquire proficiency in implementing and training diverse generative models for image, text, and graph data generation. 2. Apply state-of-the-art techniques in Generative AI to tackle complex problems in computer vision, medical image analysis, natural language processing, and graph data analysis.
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### **Text Books:**

1. Dive into Deep Learning by Aston Zhang, Zachary C. Lipton, Mu Li, and Alexander J. Smola, Cambridge University Press, 2023.
2. Deep Learning by Ian Goodfellow and Yoshua Bengio and Aaron Courville, MIT Press, 2016.

#### **Reference Books:**

1. Various research papers at prestigious venues like NIPS, ICML, ICLR, CVPR etc.

<b>Course Number</b>	MA6105 (DE)
<b>Course Credit (L-T-P-C)</b>	3-0-0-3
<b>Course Title</b>	Rings and Modules
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	Readers of this course will be well-equipped with basic concepts of Rings & Modules which are prerequisites to the courses on Fields and Galois Theory, Coding Theory, Cryptography, Homological Algebra, Noncommutative Algebra, Algebraic Geometry, and advanced courses on Analysis.
<b>Course Description</b>	It gives a foundation for further studies in algebra by discussing several classes of rings and modules. This course includes structure theorems for modules over PID, Artinian and Noetherian rings and modules, and their radicals. Further, the concept of Tensor product, Projective and Injective Modules are also introduced.
<b>Course Content</b>	Modules, submodules, quotient modules and module homomorphisms, Generation of modules, direct sums and free modules, simple modules Finitely generated modules over principal ideal domains. Ascending Chain Condition and Descending Chain Condition, Artinian and Noetherian rings and modules, Hilbert basis theorem, Primary decomposition of ideals in Noetherian rings. Radicals: Nil radical, Jacobson radical and prime radical, Localization of rings and modules. Tensor products of modules; Exact sequences, Projective, injective and flat modules.
<b>Learning Outcome</b>	On successful completion of the course, students should be able to: 1. Understand, apply and analyze the notion of rings, ideals, and modules in related concepts required for advanced courses and research in Algebra. 2. Familiar with the key properties and examples of Artinian and Noetherian rings and modules and their generalization; 3. Decide whether a given ring or module, or a class of rings or modules, is Noetherian/Artinian, by applying the characterizations discussed in the course; 4. Able to use this concept for research in Information Circuits (Coding Theory, Cryptography, Image Processing, etc.
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### Text Books:

1. C. Musili, Introduction to Rings and Modules, Narosa Pub. House, New Delhi, Sec. Edition, 2001.
2. J. A. Beachy, Introduction to Rings and Modules, London Math. Soc., Cam. Univ. Press, 2004.
3. D. S. Dummit and R. M. Foote, Abstract Algebra, 2nd Ed., John Wiley, 2002.

#### Reference Books:

1. N. Jacobson, Basic Algebra I and II, 2nd Ed., W. H. Freeman, 1985 and 1989.
2. S. Lang, Algebra, 3rd Ed., Springer (India), 2004.

<b>Sl. No.</b>	<b>Subject Code</b>	<b>Department Elective - III</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
1.	MA6106	Large Language Models (LLMs)	2	0	2	3
2.	MA6107	Number Theory	3	0	0	3
3.	MA6108	Stochastic Calculus for Finance	3	0	0	3

<b>Course Number</b>	MA6106 (DE)
<b>Course Credit (L-T-P-C)</b>	2-0-2-3
<b>Course Title</b>	Large Language Models (LLMs)
<b>Learning Mode</b>	Lectures and Labs
<b>Learning Objectives</b>	1. Master neural network architectures for time series analysis and natural language processing. 2. Understand advanced techniques in language modeling for text generation and understanding.
<b>Course Description</b>	Explore neural networks for time series analysis, delve into advanced architectures like Transformers, BERT, and GPT, and examine emerging concepts in language models for text generation.
<b>Course Outline</b>	<p>Basics of ML/DL: Classification, Regression, Training, Testing, Model selection and over/underfitting, Performance parameters, Fully Connected Neural Networks (FCNN); Time series and Recurrent Neural Networks: Time Series, NLP, FCNN and its limitation with time series analysis, RNN, LSTM, GRU, Word2vec and Glove; Architecture of Transformer Networks: Drawbacks of Recurrent Neural Networks, Self Attention, Transformers.</p> <p>BERT the encoder of Transformer Network: The basic idea and working of BERT, masked language modeling, Next Sentence prediction, Tokenization, Fine-tuning BERT, Tiny BERT, DistilBERT, RoBERTa, ELECTRA, T5; GPT the decoder of Transformer Network: Generalized Pre-Training modeling and its Training, ChatGPT: Exploring Its Applications and Advancements, Prompt Engineering, Llama and making DoctorGPT, Challenges and upcoming big issues.</p> <p>Some popular models/pipelines/concepts in LLMs: Falcon, Gemini, Gemma, Lamda, Mistral, Retrieval Augmented Generation (RAG) pipeline, Hallucinations, Knowledge Graphs, Fine-tuning LLMs with LoRA and QLoRA, Carbon Emissions and Large Neural Network Training, MiniLLM, Large Action Models, etc.</p>
<b>Learning Outcome</b>	1. Develop skills in implementing neural networks for time series forecasting and sentiment analysis. 2. Apply state-of-the-art techniques in language modeling to generate high-quality text outputs for various applications.
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE
<b>Prerequisites</b>	Linear algebra, Probability and Statistics

### Text Books:

1. Jay Alammar, Maarten Grootendorst, Hands-On Large Language Models: Language Understanding and Generation, O'Reilly Media.
2. Denis Rothman, Transformers for Natural Language Processing: Build innovative deep neural network architectures for NLP with Python, PyTorch, TensorFlow, BERT, RoBERTa, and more, Packt.
3. Denis Rothman , Transformers for Natural Language Processing and Computer Vision: Explore Generative AI and Large Language Models with Hugging Face, ChatGPT, GPT-4V, and DALL-E3, Packt.

<b>Course Number</b>	MA6107 (DE)
<b>Course Credit (L-T-P-C)</b>	3-0-0-3
<b>Course Title</b>	Number Theory
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	Readers of this course will be well-equipped with basic concepts of numbers, their properties, and some of the standard results that are fundamental to any branch of mathematics. The course will study further properties and some advanced concept which has a lot of applications in Cryptography.
<b>Course Description</b>	This course introduces divisibility in integers and some knowledge of the arithmetic of congruences. In this course, we will discuss about the congruences, arithmetic functions and their applications. Further we will study two square, four square theorem and continued fractions.
<b>Course Content</b>	(Review: Divisibility, Basic Algebra of Infinitude of primes, discussion of the Prime Number Theorem, infinitude of primes in specific arithmetic progressions, Dirichlet's theorem (without proof).) Congruences and its properties, Structure of units modulo $n$ , Binary and decimal representations of integers, linear congruences, Chinese remainder theorem, Fermat's theorem, Wilson's theorem, Fermat-Kraitchik factorization method, Number theoretic functions, Multiplicative function, Mobius inversion formula, Euler's phi function, Euler's theorem, Properties of Phi-function (Gaus theorem), Primitive roots for primes, Composite numbers having primitive roots, Indices, Quadratic residues, Legendre symbol and their properties, Law of quadratic reciprocity, Numbers of special form, Nonlinear Diophantine equation, Pythagorean triple, Fermat's method of infinite descent, Fermat's two square theorem, Lagrange's four square theorem. Continued fractions, Rational approximations, Transcendental numbers, Transcendence of "e" and "pi", Pell's equation.
<b>Learning Outcome</b>	On successful completion of the course, students should be able to: 1. Understand the importance of integers; 2. Understand other basic courses of mathematics, like Algebra, Topology, Calculus, Analysis, Geometry and Combinatorics;
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### **Text Books:**

1. David M. Burton, Elementary Number Theory, 6th Edition, McGraw Hill Higher Education, 2007.
2. Thomas Koshy, Elementary Number Theory with Applications, 2nd Edition, Academic Press, 2007.
3. I. Niven and H.S. Zuckerman, An Introduction to the Theory of Numbers, 5th Ed., Wiley, New York, 2008.

#### **Reference Books:**

1. W. W. Adams and L.J. Goldstein, Introduction to the Theory of Numbers, 3rd ed., Wiley Eastern, 1972.
2. A. Baker, A Concise Introduction to the Theory of Numbers, Cambridge University Press, Cambridge, 1984.

<b>Course Number</b>	MA6108 (DE)
<b>Course Credit (L-T-P-C)</b>	3-0-0-3
<b>Course Title</b>	Stochastic Calculus for Finance
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	In this subject, the students will be trained in approaches and concepts from stochastic calculus which are required to model as well as solve the problems in quantitative finance.
<b>Course Description</b>	This course explores the fundamentals of probability theory and various other mathematical concepts from stochastic calculus which is specifically relevant to the problems arising in mathematical finance, such as pricing of financial assets and financial derivatives.
<b>Course Content</b>	Probability spaces, filtrations, conditional expectations, martingales, stopping times; Markov process, Brownian motion; Stochastic differential equations; Ito process, Ito integral, Ito-Doeblin formula; Black-Scholes-Merton equation: derivation and solution; Risk-neutral valuation, risk-neutral measure, Girsanov's theorem, martingale representation theorem, fundamental theorems of asset pricing; Risk-neutral valuation of European, American and exotic derivatives; Greeks, implied volatility, volatility smile; Fixed income markets, interest rate models, pricing of fixed income securities, term structure; Forward rate models, Heath-Jarrow-Morton framework; Swaps, caps and floors and swap market models, LIBOR.
<b>Learning Outcome</b>	On successful completion of the course, students should be able to: 1. Understand the fundamentals of stochastic calculus. 2. Describe the concept of probability theory used in stochastic calculus 3. Comprehend and apply stochastic calculus in financial market problems, such as risk-neutral pricing and financial derivatives.
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### **Text Books:**

1. Gopinath Kallianpur, and Rajeeva L. Karandikar, Introduction to Option Pricing Theory, Birkhäuser, 2000
2. Thomas Mikosh, Elementary Stochastic Calculus, with Finance in View, World Scientific, 1998.

#### **References Books:**

1. S. Shreve, Stochastic Calculus for Finance, Vol. I, Springer, 2004.
2. S. Shreve, Stochastic Calculus for Finance, Vol. II, Springer, 2004.



<b>Sl. No.</b>	<b>Subject Code</b>	<b>SEMESTER II</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
1.	MC5201	Advanced Artificial Intelligence	3	0	0	3
2.	MC5202	Numerical Linear Algebra and Optimization Techniques	2	0	2	3
3.	MC5203	Advance Artificial Intelligence Lab	0	1	2	2
4.	XX52PQ/ XX62PQ	DE-IV	3	0	0	3
5.	XX52PQ/ XX62PQ	DE-V	3	0	0	3
6.	XX52PQ/ XX62PQ	DE-VI	3	0	0	3
7.	RM6201	Research Methodology	3	1	0	4
8.	IK6201	Indian Knowledge System	3	0	0	3
	<b>TOTAL</b>		<b>20</b>	<b>2</b>	<b>4</b>	<b>24</b>

Course Number	MC5201
Course Credit	3-0-0-3
Course Title	<b>Advanced Artificial Intelligence</b>
Learning Mode	Offline
Learning Objectives	<ul style="list-style-type: none"> <li>• To understand the principles of Artificial Intelligence and the nature of intelligent agents.</li> <li>• To learn various problem-solving techniques, including informed search and exploration.</li> <li>• To gain proficiency in handling constraint satisfaction problems and adversarial search.</li> <li>• To develop a solid foundation in knowledge representation, first-order logic, and propositional logic.</li> <li>• To learn to plan and act effectively in real-world AI applications.</li> <li>• To grasp the concepts of uncertain knowledge and probabilistic reasoning.</li> <li>• To make informed decisions using simple and complex decision-making models.</li> <li>• To acquire skills in learning from observations and applying statistical learning methods.</li> <li>• To explore advanced AI techniques and their practical applications.</li> </ul>
Course Description	<p>This course offers an in-depth exploration of advanced concepts in Artificial Intelligence (AI). Students will delve into the theoretical underpinnings and practical applications of AI, examining intelligent agents, the nature of environments, and advanced problem-solving techniques. The curriculum covers informed search and exploration, constraint satisfaction problems, adversarial search, and knowledge representation. Students will also explore reasoning with first-order and propositional logic, planning and acting in real-world scenarios, and handling uncertainty through probabilistic reasoning. The course concludes with statistical learning methods and advanced AI techniques, providing a comprehensive understanding of AI's capabilities and applications.</p>
Course Outline	<p>Introduction and motivation Artificial Intelligence, intelligent agents, nature of environments,  Problem-solving by searching, informed search and exploration, constraint satisfaction problem, adversarial search,  Knowledge and reasoning, first order logic, inference and propositional logic, knowledge representation,  Planning and acting in real world of AI agent  Uncertain knowledge and reasoning, uncertainty, probabilistic reasoning, making simple and complex decisions  Learning from observations and knowledge, statistical learning methods,  Some advanced techniques of AI and its applications</p>

Learning Outcome	<p>Upon completing this course, students will be able to:</p> <ul style="list-style-type: none"> <li>• Analyze and implement intelligent agents in various environments.</li> <li>• Apply informed search techniques to solve complex problems.</li> <li>• Formulate and solve constraint satisfaction problems and engage in adversarial search strategies.</li> <li>• Represent and reason with knowledge using first-order and propositional logic.</li> <li>• Develop and execute plans in real-world AI scenarios.</li> <li>• Manage uncertainty and employ probabilistic reasoning to make sound decisions.</li> <li>• Utilize statistical learning methods to derive insights from data.</li> <li>• Implement advanced AI techniques in real-world applications.</li> <li>• Demonstrate a comprehensive understanding of advanced AI concepts and their implications.</li> </ul>
Assessment Method	Internal(Quiz/Assignment/Project), Mid-Term, End-Term

### **Suggested Reading**

- Russell, S. J., & Norvig, P. (2016). Artificial intelligence: A modern approach. Pearson.
- Poole, D. L., & Mackworth, A. K. (2010). Artificial Intelligence: foundations of computational agents. Cambridge University Press.
- Hastie, T., Tibshirani, R., Friedman, J. H., & Friedman, J. H. (2009). The elements of statistical learning: data mining, inference, and prediction (Vol. 2, pp. 1-758). New York: Springer.

<b>Course Number</b>	MC5202 (Core)
<b>Course Credit</b>	3-0-2-4
<b>Course Title</b>	Numerical Linear Algebra and Optimization Techniques
<b>Learning Mode</b>	Lectures and Labs
<b>Learning Objectives</b>	The objective of the course is to train students about the different numerical techniques to solve linear equations, linear least square problems and find eigen values of matrices as well as check the stability of numerical methods. Moreover, students would be able to perform modeling of convex programming problems and employ various classical and numerical optimization techniques and algorithms to solve these problems
<b>Course Description</b>	Numerical Linear Algebra and Optimization Techniques, as a basic subject for postgraduate students, provides the knowledge of various numerical techniques to solve linear equations as well as check the stability of numerical methods. Moreover, this course would help the students to models convex optimization problems and learn different algorithms to solve such problems with its applications in various problems arising in economics, science and engineering.
<b>Course Content</b>	<p>Review of matrix Algebra, Norms and condition numbers of Matrix, Systems of Equations, Gaussian Elimination, LU, PLU and Cholesky Factorization, Iterative Solvers: Jacobi, Gauss Seidel, SOR and their convergence, Gram-Schmidt orthogonalization</p> <p>QR Factorization and Least Squares, Eigenvalues, Power method, Reduction to Hessenberg or Tridiagonal form, Rayleigh quotient, inverse iteration, QR Algorithm without and with shifts,</p> <p>Singular Value Decomposition and Its applications</p> <p>Introduction to nonlinear programming, Convex Sets, Convex Functions and their properties. Unconstrained optimization of functions of several variables: Classical techniques. Numerical methods for unconstrained optimization: One Dimensional Search Methods, Golden Section Search and Fibonacci search, Basic descent methods, Conjugate direction, Newton's and Quasi-Newton methods</p> <p>Constrained optimization of functions of several variables, Lagrange Multiplier method, Karush-Kuhn-Tucker theory, Constraint Qualifications, Convex optimization</p> <p>Merit functions for constrained minimization, logarithmic barrier function for inequality constraints, A basic barrier-function algorithm</p> <p>Practice of algorithms using Software.</p>
<b>Learning Outcome</b>	<p>On successful completion of the course, students should be able to:</p> <ol style="list-style-type: none"> <li>1. Understand different Matrix factorization method and employ them to solve linear equations and linear least square problems</li> <li>2. To comprehend the basic computer arithmetic and the concepts of conditioning and stability of a numerical method.</li> <li>3. Understand the terminology and basic concepts of various kinds of convex optimization problems and solve different solution methods to solve convex Programming problem.</li> <li>4. Apply and differentiate the need and importance of various algorithms to solve convex programming problems</li> <li>5. Employ programming languages like MATLAB to solve linear equations, find eigen values and convex programming problems</li> <li>6. Model and solve several problems arising in science and engineering as a convex optimization problem</li> </ol>
<b>Assessment Method</b>	Quiz / Assignment / MSE / ESE

**Text Books:**

1. Lloyd N. Trefethen, David Bau III: Numerical Linear Algebra, 1st Edition, SIAM, Philadelphia (1997)
2. Edwin K. P. Chong, Stanislaw H. Zak: An Introduction to Optimization, 4<sup>th</sup> Edition, Wiley India (2017)

3. Gilbert Strang: Lecture Notes for Linear Algebra, Wellesley Cambridge Press, SIAM (2021)

**Reference Books:**

1. Stephan Boyd and Lieven. Vandenberghe: Convex Optimization, Cambridge University Press (2004)
2. Singiresu S. Rao: Engineering Optimization Theory and Practice, John Wiley & Sons (2019)

Course Number	MC5203
Course Credit	0-1-2-2
Course Title	<b>Advanced Artificial Intelligence Lab</b>
Learning Mode	Offline
Learning Objectives	<ul style="list-style-type: none"> <li>• To implement the techniques and algorithms learnt in Advance Artificial Intelligence theory</li> <li>• To analyze advanced AI techniques and their practical applications.</li> </ul>
Course Description	This course offers an in-depth exploration and practical implementation of advanced concepts in Artificial Intelligence.
Course Outline	Practical implementation of algorithms and techniques learnt in Advance Artificial Intelligence theory
Learning Outcome	<p>Upon completing this course, students will be able to:</p> <ul style="list-style-type: none"> <li>• Analyze and practically implement the advanced concepts in Artificial Intelligence.</li> <li>• Demonstrate a comprehensive understanding of advanced AI concepts and their implications in real world.</li> </ul>
Assessment Method	Internal(Quiz/Assignment/Project), Mid-Term, End-Term

<b>Sl. No.</b>	<b>Subject Code</b>	<b>Department Elective - IV</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
1.	MA5201	Portfolio Theory and Risk Management	3	0	0	3
2.	MA6202	Introduction to Biomathematics	3	0	0	3
3.	MA6203	Introduction to Homological Algebra	3	0	0	3
4.	MA6204	Noncommutative Algebra	3	0	0	3
5.	MA6205	Sobolev Spaces	3	0	0	3
6.	MA6206	Wavelet Transform	3	0	0	3
7.	CS6201	Artificial Internet of Things	3	0	0	3
8.	CS6202	Game Theory	3	0	0	3
9.	CS6203	Text Mining & Analytics	3	0	0	3

<b>Course Number</b>	MA5201 (DE)
<b>Course Credit (L-T-P-C)</b>	3-0-0-3
<b>Course Title</b>	Portfolio Theory and Risk Management
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	The goal of this course are two-folds, namely design of portfolios and the identification as well as risk management of such portfolios.
<b>Course Description</b>	Portfolio theory involves the usage of techniques of probability theory and statistics in the design and analysis of a financial portfolios (such as mutual funds). On the other hand, risk management involves tools from mathematics and statistics in the identification of financial risks to portfolios and the determination of the appropriate techniques to mitigate this risk.
<b>Course Content</b>	Return and risk of a portfolio, mean-variance portfolio theory, efficient frontier, Capital Asset Pricing Model, Arbitrage Pricing Theory; Utility theory, risk attitude of investors; Non-mean-variance portfolio theory, safety first models, semi-deviation, stochastic dominance; Bond portfolios, duration and convexity of a bond. Fundamentals of financial risk management, credit risk, market risk, operational risk, Basel and Solvency regulations; Market risk, Value-at-Risk (VaR), computation of VaR, coherent measures of risk; Credit risk, modelling correlated defaults, asset value models, term structure of default probability, credit derivatives; Operational risk, loss models, extreme value theory, parametric estimation.
<b>Learning Outcome</b>	On successful completion of the course, students should be able to: 1. Understand the fundamentals of portfolio theory from asset picking to asset allocation and performance analysis of the portfolio. 2. Identification and quantification of risk of financial portfolios using mathematical and statistical tools. 3. Determination of robust techniques to mitigate the identified financial risks.
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### **Text Books:**

1. S.P. Chakrabarty and A. Kanaujiya, Mathematical Portfolio Theory and Analysis, 1st Edition Birkshauser, 2023.
2. T. Roncalli, Handbook of Financial Risk Management, CRC Press, 2020

#### **References Books:**

1. J. C. Francis and D. Kim, Modern Portfolio Theory: Foundations, Analysis, and New Developments, 1st Edition, Wiley, 2013.
- J. C. Hull, Risk Management and Financial Institutions, 4th Edition, Wiley, 2016.



<b>Course Number</b>	MA6202 (DE)
<b>Course Credit (L-T-P-C)</b>	3-0-0-3
<b>Course Title</b>	Introduction to Biomathematics
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	To learn application of Mathematics in Biology. To appreciate the representation of biological systems mathematically. To comprehend mathematical analysis and to correlate the outcome of mathematical system into biological system. To learn and understand the bridge between mathematical and biological worlds.
<b>Course Description</b>	This course is meant to expose the candidate to mathematical modeling biological systems and then apply it to various systems and analyse these models.
<b>Course Content</b>	<p><b>Mathematical modeling:</b> Role of mathematics in problem solving, Introduction to mathematical modeling and its basic concepts- system description and characterization, model formulation, validation and analysis of models, Pitfalls in modeling.</p> <p><b>Population Dynamics:</b> Deterministic models in population dynamics (Discrete and Continuous), Stochastic birth-death models and analysis.</p> <p><b>Models in ecology:</b> Predator-prey models (Discrete and Continuous), Spatio-temporal models- diffusion processes, Turing Instability; fisheries models- optimal harvesting and sustainability.</p> <p><b>Models at molecular level:</b> HIV in vivo model, immune response models, Cancer models.</p> <p><b>Modeling disease:</b> Infectious disease models, Models for non-communicable diseases (NCDs).</p> <p><b>Models for public health:</b> Diseases control and interventions, Optimal control, Cost optimization.</p> <p><b>Computational:</b> Parameter estimation, network models.</p>
<b>Learning Outcome</b>	Students will be able to apply the mathematical knowledge on a biological system, analyse it and interpret it in terms of the biological systems.
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### Text Books:

1. N. F. Britton, Essential Mathematical Biology, SUMS, Springer
2. F. Brauer and C. Castillo-Chavez, Mathematical models in population biology and epidemiology, Springer, 2012.
3. D. N. P. Murthy, N. W. Page, Ervin Y. Rodin, Mathematical modelling: a tool for problem solving in engineering, physical, biological, and social sciences, Pergamon Press, 1990.

#### Reference Books:

1. J. D. Murray, Mathematical Biology Volume I, 3rd Ed, 2003.
2. F. C. Hoppensteadt, Mathematical methods of population biology. Cambridge: Cambridge Univ. Press, 1982.

<b>Course Number</b>	MA6203 (DE)
<b>Course Credit (L-T-P-C)</b>	3-0-0-3
<b>Course Title</b>	Introduction to Homological Algebra
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	The objective of this course is equipping students with the methods of homological algebra and expose them to some of its very effective and historical applications in algebra.
<b>Course Description</b>	This course covers the basics of homological algebra. Using the tools of homological algebra, some results of commutative algebra will be discussed such as Auslander-Buchsbaum formula.
<b>Course Content</b>	Review of modules, submodules, quotient modules, homomorphism, kernel and image, Direct sum and direct product of modules, Free modules, universal properties of free modules and direct sums, Hom and Tensor product of modules, universal properties of tensor products, exact sequences, right exactness of tensor product, left exactness of Hom, local rings, algebras, graded rings and graded modules, polynomial rings. Localization of rings and modules, exactness of localisation, commutative properties of localisation with tensor product and Hom, Categories and functors, exact functors, injective, projective and flat modules, complexes and homology modules, resolution of a module, Derived functor: construction and uniqueness, the functors Ext and Tor, Projective, injective and global dimension, projective dimension over a local ring. Regular sequence for a module, depth of a module, Auslander-Buchsbaum formula with proof and examples.
<b>Learning Outcome</b>	Students will learn the methods of homological algebra systematically. They will appreciate it as an extension of their knowledge from Linear algebra. They will also be prepared to take a research project in related topics.
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### **Text Books:**

1. Balwant Singh: Basic Commutative Algebra, World Scientific Publishing Company (2011).
2. M. F. Atiyah and I. G. MacDonald: Introduction to commutative Algebra, Addison-Wesley Series in Mathematics, Westview Press (1994).
3. David Eisenbud : Commutative Algebra with a view towards Algebraic Geometry, Springer-Verlag New York (1995).

#### **Reference Books:**

1. Charles A. Weibel: An introduction to Homological Algebra, (Series Title: Cambridge Studies in Advanced Mathematics), Cambridge University Press (1995).
2. Joseph Rotman : An introduction to Homological Algebra, (Series Title: Universitext), Springer, Second edition (2009).

<b>Course Number</b>	MA6204 (DE)
<b>Course Credit (L-T-P-C)</b>	3-0-0-3
<b>Course Title</b>	Non-commutative Algebra
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	The goal of this course is to provide a fundamental knowledge of non-commutative algebra. It is intended that the students become familiar with the main basic techniques and results of this area and become ready for research projects.
<b>Course Description</b>	This course will cover theory of non-commutative algebra. It will begin with matrix rings, tensor products of matrix algebras and cover important result such as Wedderburn structure theorem. Further, simple rings, primitive rings derivations, involutions and density theorem will be discussed.
<b>Course Content</b>	Matrix Rings and PLIDs, Tensor Products of Matrix Algebras, Ring constructions using Regular Representation. Basic notions for Non-commutative Rings, Structure of $\text{Hom}(M, N)$ , Semisimple Modules & Rings, Wedderburn Structure Theorem, Simple Rings, Rings with Involution. The Jacobson Radical and its properties. Prime and Semiprime rings, Essential ideals in prime rings, Maximal Right of Ring of Quotients, The Two sided and Symmetric Rings of Quotients, The extended Centroid, Derivations and (Anti) automorphisms. Primitive Rings and Ideals, Rings of Quotients, Density Theorems, Primitive Rings with Nonzero Socle.
<b>Learning Outcome</b>	After completion of this course student will: 1) become fluent working with rings. 2) be able to understand some proofs of non-commutative algebra. 3) be able to appreciate powerful structure theorems, and be familiar with examples of non-commutative rings arising from various parts of mathematics.
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### **Text Books:**

1. L. Rowen, Graduate algebra: noncommutative view, Graduate Studies in Mathematics, 91.
2. K. I. Beidar, W. S. Martindale, A. V. Mikhalev, Rings with Generalized Identities, Monographs and Textbooks in Pure and Applied Mathematics, 196, Marcel Dekker, Inc., New York, 1996.
3. T. Y. Lam, A first course in noncommutative rings, GTM, Springer.

#### **Reference Books:**

1. B. Farb, R. Dennis, Noncommutative algebra, GTM, Springer-Verlag.
2. J. Golan and T. Head, Modules and the structure of rings: A primer, Pure and applied mathematics

<b>Course Number</b>	MA6205 (DE)
<b>Course Credit (L-T-P-C)</b>	3-0-0-3
<b>Course Title</b>	Sobolev Spaces
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	The Sobolev spaces serve as a theoretical framework for studying solutions to partial differential equations.
<b>Course Description</b>	This course deals with Sobolev Spaces and some basic properties of them and simple application on PDEs.
<b>Course Content</b>	<p><b>Distribution and Fourier Transform</b> Revision / introduction to theory of distributions and Fourier Transform</p> <p><b>Sobolev Spaces</b> The Spaces <math>W_{\infty}^{l,p}(\Omega)</math> and <math>W^{l,p}(\Omega)</math>, their simple characteristic properties, density theorems, Min and Max of <math>W^{l,p}</math> Functions, The space <math>H_m(\mathbb{R}^n)</math> and its Properties, Density results. Dual Spaces, Fractional Order Sobolev Spaces, Poincare theorem, Stampaccia Theorem, Trace spaces and Trace Theory.</p> <p><b>Imbedding Theorem</b> Sobolev Lemma, Continuous and compact imbedding of Sobolev spaces into Lebesgue Spaces, Rellich Weighted Spaces</p> <p><b>Applications to elliptic PDE</b> Abstract Variational problems, Lax-Milgram lemma, weak solutions and well posedness with examples, regularity result, maximum principles, eigenvalue problems.</p>
<b>Learning Outcome</b>	Students should be able to realize the importance of Sobolev spaces and should be able to define them and shall be able to prove existence of weak solutions for a class of PDEs.
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### Text Books:

1. Kesavan S.: Topics in Functional Analysis and Applications. New Age International Private Limited, January 2015.
2. Pathak R. S.: A Course in Distribution Theory and Applications. Narosa publishing House, 2001.

#### Reference Books:

1. Renardy M. and Rogers R.C., An Introduction to Partial Differential Equations. Springer, 2004.
2. Lieb and Loss, Analysis: Second Edition, American Mathematical Society, 2001.

<b>Course Number</b>	MA6206 (DE)
<b>Course Credit (L-T-P-C)</b>	3-0-0-3
<b>Course Title</b>	Wavelets Transform
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	Learn about Fourier Transform, its draw back and extension of concepts of Fourier to Wavelets.
<b>Course Description</b>	Details of various transforms will be discussed that is required to understand Wavelet transform. Definition of Wavelets, Wavelet Basis, Multiresolution Analyses will be discussed throughout the course. At the end we shall learn how to solve ODEs and PDEs with help of Wavelets.
<b>Course Content</b>	<p>Fourier Transforms, Poisson's Summation Formula, The Shannon Sampling Theorem, Heisenberg's Uncertainty Principle, The Gabor Transform, The Zak Transform, The Wigner-Ville Distribution, Ambiguity Functions.</p> <p>Wavelet Transforms, Continuous Wavelet Transforms, Basic Properties, The Discrete Wavelet Transforms, Orthonormal Wavelets, Multiresolution Analysis and Construction of Wavelets, Properties of Scaling Functions and Orthonormal Wavelet Bases, Construction of Orthonormal Wavelets, Daubechies' Wavelets, Mallat's Theorem, Wavelet Expansions and Parseval's Formula.</p> <p>Application: Solutions of ODEs and PDEs by using wavelets.</p>
<b>Learning Outcome</b>	<p>On successful completion of the course, students should be able to:</p> <ol style="list-style-type: none"> <li>1. Differentiate between advantages and disadvantage of Fourier and Wavelets transform.</li> <li>2. They shall be able to construct orthonormal basis of <math>L^2(\mathbb{R})</math>.</li> <li>3. They shall be able to solve some ODEs and PDEs using Wavelets.</li> </ol>
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### **Text Books:**

1. Lokenath Debnath, Wavelet Transforms and Their Applications, Springer Science+Business, Media, New York, 2002.
2. María Cristina Pereyra, Lesley A. Ward, Harmonic Analysis: From Fourier to Wavelets, AMS Book, Student Mathematical Library, IAS/Park City Mathematical Subseries, Volume 63.

#### **Reference Books:**

1. C. K. Chui, An Introduction to Wavelets, Academic Press, 1992.
2. Daubechies, Ten Lectures on Wavelets, SIAM Publication, Philadelphia, 1992.

<b>Sl. No.</b>	<b>Subject Code</b>	<b>Department Elective - V</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
1.	MA6207	Differential Manifolds	3	0	0	3
2.	MA6208	Graph Algorithms	3	0	0	3
3.	MA6209	Numerical solutions of PDEs	2	0	2	3
4.	MA6210	Statistical Inference	3	0	0	3
5.	MA6217	Database and Data Mining	2	0	2	3
6.	CS6204	Knowledge Distillation	3	0	0	3
7.	CS6205	Physics of Neural Network	3	0	0	3
8.	CS6206	Selected Topics in Wireless Networks	3	0	0	3
9.	CS6207	Advanced Big Data Analytics	3	0	0	3

<b>Course Number</b>	MA6207 (DE)
<b>Course Credit (L-T-P-C)</b>	3-0-0-3
<b>Course Title</b>	Differential Manifolds
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	Same as Learning Outcome
<b>Course Description</b>	It is a basic introductory course in the theory of smooth manifolds.
<b>Course Content</b>	<p>The derivative, continuously differentiable functions, the inverse function theorem, the implicit function theorem.</p> <p>Topological manifolds, partitions of unity, imbedding and immersions, manifolds with boundary, submanifolds.</p> <p>Tangent vectors and differentials, Sard's theorem and regular values, Local properties of immersions and submersions.</p> <p>Vector fields and flows, tangent bundles, Embeddings in Euclidean spaces, smooth maps and their differentials.</p> <p>Smooth manifolds, smooth manifolds with boundary, smooth submanifolds, construction of smooth functions, classical Lie groups.</p>
<b>Learning Outcome</b>	<p>At the end of this course, students should be able to:</p> <ul style="list-style-type: none"> <li>-compute the atlases of several important examples of smooth manifolds.</li> <li>-compute the derivatives of smooth functions defined on smooth manifolds.</li> </ul>
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### **Text Books:**

1. J. M. Lee, Manifolds and Differential Geometry, AMS, GSM, 2014.
2. G. E. Bredon, Topology and Geometry, Springer-verlag, 1993.
3. A. Kosinski, Differential Manifolds, Academic Press, 1992.

#### **Reference Books:**

1. J. R. Munkres, Analysis on Manifolds, Addison-Wesley Publishing Company, 1991.
2. M. Spivak, A Comprehensive Introduction to Differential Geometry I, Publish or Perish, 1979.

<b>Course Number</b>	MA6208 (DE)
<b>Course Credit</b>	3-0-0-3
<b>Course Title</b>	Graph Algorithms
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	To learn various notions in graph theory and their application in real life situation and to learn different algorithms to solve optimization problems in graph theory.
<b>Course Description</b>	This course is meant to introduce various notions in graph theory and their application.
<b>Course Outline</b>	<p>(Review of Basic definitions in graph theory, Trees, Connectivity, Spanning trees, Shortest Path Problems, Eulerian and Hamiltonian graphs, Planar graphs, Graph Coloring)</p> <p>Graph searching algorithm: Breadth first search (BFS), Depth first search (DFS) and their applications.</p> <p>Algorithms for spanning tree: Kruskal's algorithm, Prim's algorithm</p> <p>Algorithms for shortest path: Dijkstra's algorithm, Bellman-Ford algorithm, Floyd-Warshall algorithm</p> <p>Matching, Konig Theorem, Algorithm to find maximum matching in bipartite graphs, Hall's theorem, Matching in non-bipartite graph: Edmond's blossom algorithm.</p> <p>Network flow, Max flow-min cut theorem, Ford-Fulkerson algorithm.</p> <p>Graph coloring, Greedy coloring technique, Variations of graph coloring</p> <p>Independent set, Clique, Dominating set and corresponding optimization problems.</p> <p>Probabilistic methods, Alteration technique, Applications of linearity of expectation and conditional expectation in graph theory.</p> <p>Notion of the class P, NP and NP-complete with examples</p>
<b>Learning Outcome</b>	Students will be accustomed to the basic graph algorithms. Using graph theory, they will be able to model different real-life problems. Also, implementing the algorithms taught in the course, they can even solve those real-life problems.
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

### Text Books:

1. Introduction to Graph Theory by D. B. West, Pearson Prentice Hall.
2. Graph Theory by Reinhard Diestel, Graduate Texts in Mathematics, Springer, 5<sup>th</sup> Edition.
3. Graph Algorithms by Shimon Even, Cambridge University Press.

### Reference Books:

1. Algorithm Design by J. Kleinberg and Eva Tardos, Pearson Education
2. Introduction to Algorithms by T. H. Cormen, C. E. Leiserson, R. L. Rivest and C. Stein, Prentice Hall India.



<b>Course Number</b>	MA6209 (DE)
<b>Course Credit (L-T-P-C)</b>	2-0-2-3
<b>Course Title</b>	Numerical solutions of PDEs
<b>Learning Mode</b>	Lectures and Labs
<b>Learning Objectives</b>	In this subject, the students will be trained with the knowledge of Computing of the approximate solutions of partial differential equations.
<b>Course Description</b>	This course involves difference equations to solve differential equations by algorithms
<b>Course Content</b>	<p>Introduction to Finite differences: Mesh points (uniform/nonuniform), Finite-difference approximations of integrals and derivatives, Order of convergence.</p> <p>Linear Transport Equation, Upwind Scheme, Central scheme, Midpoint Scheme, Lax- Wendroff and Lax-Friedrich schemes, CFL condition, Lax-Richtmyer equivalence theorem, Diffusion, Dissipation, Dispersion.</p> <p>Introduction to Von- Neumann stability analysis and Matrix analysis.</p> <p>General Parabolic Equation (1D &amp; 2D): Initial and boundary value problems (Dirichlet and Neumann), Explicit and implicit methods (Backward Euler and Crank-Nicolson schemes) with consistency and stability, Discrete maximum principle, ADI methods for two dimensional heat equation including Method of Lines.</p> <p>General Elliptic Equation (1D &amp; 2D): Finite difference scheme for initial and boundary value problems, Discrete maximum principle, Peaceman-Rachford algorithm (ADI) for linear systems.</p> <p>Wave Equation (1D &amp; 2D): Explicit schemes and their stability analysis, Implementation of boundary conditions.</p> <p>Exposure on writing computational algorithm.</p>
<b>Learning Outcome</b>	From this course, students will learn – how to solve partial differential equations and their convergence analysis
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### **Text Books:**

1. J. C. Strikwerda, Finite Difference Schemes and Partial Differential Equations, SIAM, 2004.
2. W. Morton and D. F. Mayers, Numerical Solution of Partial Differential Equations, Cambridge University Press, 2nd Edn., 2005.
3. Zhilin Li, Zhonghua Qiao, Tao Tang, Numerical Solution of Differential Equations, Cambridge University Press, 2017.

#### **Reference Books:**

1. Mark S. Gockenbach, Partial Differential Equations: Analytical and Numerical Methods, 2nd Edition, SIAM.
2. R. M. M. Mattheij, S. W. Rienstra, J. H. M. T. T. Boonkkamp, Partial Differential Equations: Modeling, Analysis, Computation, SIAM, 2005.

<b>Course Number</b>	MA6210 (DE)
<b>Course Credit (L-T-P-C)</b>	3-0-0-3
<b>Course Title</b>	Statistical Inference
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	Students will learn basic concepts of statistics which are significantly important in statistical analysis. One of the main goals of this course is to build background in theoretical statistics.
<b>Course Description</b>	Various estimation methods will be discussed and their error behavior will be studied. Some of important hypothesis testing problems will also be discussed.
<b>Course Outline</b>	Sampling distributions, Basic Concepts of estimation problems, Order statistics and their distributions, Sufficiency, Factorization method, minimal sufficient statistic, exponential families, unbiased estimators and properties, mean square error, Rao-Blackwell Theorem, Lehmann-Scheffe Theorem, Method of moments estimators, Maximum likelihood estimation and invariance property, Consistent estimators, Fisher information, Cramer-Rao inequality, confidence intervals, pivotal quantities, Examples of interval estimation. Tests of hypotheses, simple and composite hypotheses, critical regions, Type I and II errors, Power of a test, significance probabilities, size of a test, monotone likelihood ratio property and examples, Neyman-Pearson Lemma, uniformly most powerful tests, likelihood ratio tests, chi-square tests.
<b>Learning Outcome</b>	From this course students will be able to learn basics of theoretical statistics. They will learn various inference methods and will understand their comparative behavior.
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### **Text Books:**

1. R. L. Berger and G. Casella, Statistical Inference, Duxbury Advanced Series, Second Edition, 2007.
2. A. M. Mood, F. A. Graybill and D. C. Boes, Introduction to the Theory of Statistics, Tata McGraw-Hill, 2009.

#### **Reference Book:**

1. V. K. Rohatgi & A. K. Md. E. Saleh, An Introduction to Probability and Statistics. John-Wiley, Second Edition, 2009.

<b>Course Number</b>	MA6217 (DE)
<b>Course Credit</b>	2 – 0 – 2 – 3
<b>Course Title</b>	Database and Data Mining
<b>Learning Mode</b>	Lectures and Labs
<b>Learning Objectives</b>	Understand database fundamentals, SQL operations, and relational database design principles for effective data management. Acquire proficiency in data mining techniques, including classification, clustering, and association rule mining, and apply them to solve real-world problems.
<b>Course Description</b>	Explore databases, SQL, and relational design principles, alongside data mining techniques for practical analysis and problem-solving.
<b>Course Content</b>	<p><b>Database:</b> Introduction to database, Structured Query Language (SQL), Relational Algebra, Entity-Relationship Model, Relational Database Design, Case Studies, Functional Dependency and Normal Forms, Storage and File Structure, Indexing and Hashing, Query Processing, Query Optimization. Transactions (Serializability and Recoverability), Concurrency Control, Recovery Systems</p> <p><b>Data Mining:</b> Knowledge Mining from Databases, Data Pre-processing, Multi-dimensional data Modeling, Classification and Prediction, Clustering, Frequent item-set Mining, Outlier Detection, Mining special kinds of data including Text and Graph, OLAP</p>
<b>Learning Outcome</b>	<p><b>1. Understanding:</b> Gain knowledge of database fundamentals, SQL operations, and relational design principles.</p> <p><b>2. Proficiency:</b> Develop skills in data mining techniques such as classification, clustering, and association rule mining for practical analysis and problem-solving.</p>
<b>Assessment Method</b>	Quiz / Assignment / MSE / ESE

#### Textbooks:

1. H Garcia-Molina, JD Ullman and Widom, Database Systems: The Complete Book, 2<sup>nd</sup> Ed., Prentice-Hall, 2008.
2. A Silberschatz, H Korth and S Sudarshan, Database System Concepts, 6th Ed., McGraw-Hill, 2010

#### Reference Books:

1. R Elmasri, S Navathe, Fundamentals of Database Systems, 6th edition, Addison-Wesley, 2010.
2. R Ramakrishnan, J Gehrke, Database Management Systems, 3rd Ed., McGraw-Hill, 2002.
3. Hand David, MannilaHeikki, and Smyth Padhraic. Principles of Data Mining. Boston, MA: MIT, 2004. ISBN: 8120324579.
4. M. H. Dunham. Data Mining: Introductory and Advanced Topics. Pearson Education. 2001.
5. Samatova, N. F., Hendrix, W., Jenkins, J., Padmanabhan, K., & Chakraborty, A. (Eds.). (2013). Practical Graph Mining with R. CRC Press.
6. Data Mining: Concepts and Techniques" by Jiawei Han and Micheline Kamber, Elsevier, 2006.

<b>Sl. No.</b>	<b>Subject Code</b>	<b>Department Elective - VI</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
1.	MA5203	Discrete Mathematics	3	0	0	3
2.	MA6211	Advanced Complex Analysis	3	0	0	3
3.	MA6212	Algebraic Coding Theory	3	0	0	3
4.	MA6213	Finite Element Analysis	3	0	0	3
5.	MA6214	Introduction to Algebraic Geometry	3	0	0	3
6.	MA6215	Operators on Hilbert Spaces	3	0	0	3
7.	MA6216	Riemannian Geometry	3	0	0	3
8.	CS6208	Quantum Machine Learning	3	0	0	3
9.	CS6209	Meta Learning	3	0	0	3
10.	CS6210	Selective Topics in Generative AI	3	0	0	3

<b>Course Number</b>	MA5203 (DE)
<b>Course Credit</b>	3-0-0-3
<b>Course Title</b>	Discrete Mathematics
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	To learn formal mathematical way of writing through mathematical logic and different counting techniques through examples
<b>Course Description</b>	This course is meant to introduce different counting techniques. It also covers introductory graph theory and Boolean algebra.
<b>Course Outline</b>	<p>Mathematical Logic and Proofs: Propositional logic and equivalences, Predicate and Quantifiers, Introduction to Proofs, Proof methods Sets, Relations and Functions: Relations and their properties, Closure of Relations, Order Relations, Equivalence relations, POSets, Mobius function of POSets, Lattices, Distributive lattices.</p> <p>Counting Techniques: Permutations and Combinations, Binomial coefficients, Pigeonhole principle, Double counting, Principle of Inclusion-Exclusion, Recurrence relations and its solution, Divide and Conquer, Generating functions.</p> <p>Graph Theory: Basic definitions, Trees, Connectivity, Spanning trees, Shortest Path Problems, Eulerian and Hamiltonian graphs, Planar graphs, Graph Coloring</p> <p>Boolean Algebra: Boolean functions, Logic gates, Simplification of Boolean Functions, Boolean Circuits</p>
<b>Learning Outcome</b>	Students will be accustomed with the formal mathematical way of writing. They will also be able to apply counting techniques to different problems. Using graph theory, they will be able to model different real-life problems as well.
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### **Text Books:**

1. Discrete Mathematics and Its Applications by K. H. Rosen, Tata McGraw-Hill
2. Basic Techniques of Combinatorial Theory by D. I. A. Cohen, John Wiley & Sons
3. Introduction to Graph Theory by D. B. West, Pearson Prentice Hall

#### **Reference Books:**

1. A Walk Through Combinatorics by Miklos Bona, 4th Edition, World Scientific
2. Invitation to Discrete Mathematics by J. Matousek and J. Nešetřil, Oxford University Press

<b>Course Number</b>	MA6211 (DE)
<b>Course Credit (L-T-P-C)</b>	3-0-0-3
<b>Course Title</b>	Advanced complex analysis
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	Same as learning outcome
<b>Course Description</b>	This is an advanced course on complex analysis. In this course we will study some global properties of analytic functions and discuss some important examples of meromorphic functions.
<b>Course Content</b>	Conformal mappings, the Maximum principle of analytic functions; a general form of Cauchy's theorem, Harmonic functions; Mean-value property, Schwarz's reflection principle, Weierstrass factorization theorem, The Gamma function, Stirling's formula; Hadamard's theorem, Normal families, The Riemann mapping theorem, Harnack's principle, The Dirichlet problem, Elliptic functions and their properties, the Weierstrass- <b>P</b> function, global properties of analytic functions; analytic continuation, Picard's theorem.
<b>Learning Outcome</b>	At the end of this course, students should be able to: <ul style="list-style-type: none"> <li>- compute factorization of a general analytic function (which may have infinitely many factors).</li> <li>- Understand important properties of some special complex analytic functions, which find their application in analytic number theory and geometry.</li> </ul>
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### **Text Books:**

1. Complex Variables and Applications: James Ward Brown and Ruel V. Churchill, 8th Edition, McGraw Hills.
2. Complex Analysis: Lars V Ahlfors, McGraw Hill Education; Third edition (July 2017)
3. Complex Analysis: Elias M. Stein and Rami Shakarchi, Princeton University Press (23 May 2003)

#### **Reference Books:**

1. Joseph L. Taylor, Complex Variables - American Mathematical Society, 2011.
2. Edward C. Titchmarsh, The Theory of Functions, Oxford University Press; 2 edition, 1976.

<b>Course Number</b>	MA6212 (DE)
<b>Course Credit (L-T-P-C)</b>	3-0-0-3
<b>Course Title</b>	Algebraic Coding Theory
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	Readers of this course will be well-equipped with the application of the basics of mathematics, specially, Algebra, Number Theory and Probability Theory in Information Theory.
<b>Course Description</b>	It gives a foundation for further studies in information communications. This course includes different codes such as binary codes, Hamming codes, linear codes (cyclic codes in detail), and nonlinear codes, with different bounds by using mathematical tools, which are essential to understand an information communication system.
<b>Course Content</b>	Polynomial rings over fields, Extension of fields, Computation in $GF(q)$ , $n$ -th roots of unity, Vector space over finite fields. Error Detection, correction and decoding. Linear block codes: Hamming weight, Generator and Parity-check matrix Encoding and Decoding of linear codes, Bounds: Sphere-covering bound, Gilbert-Varshamov bound, Hamming bound, Singleton bound, Plotkin bound. Hamming codes, Simplex codes, Golay codes, First and Second order Reed-Muller codes. Nonlinear codes: Hadamard codes, Preparata codes, Kerdock codes, Nordstrom-Robinson code, Weight distribution of codes. The structure of cyclic codes, Roots of Cyclic Codes, Decoding of cyclic codes, Burst-error-correcting codes, Constacyclic and quasi-cyclic codes, skew cyclic codes, Quadratic residue codes, BCH codes, RS codes, GRS codes. Generalized BCH codes. Self-dual codes and invariant theory, Covering radius problem, Convolutional codes, LDPC codes, Turbo codes.
<b>Learning Outcome</b>	On successful completion of the course, students should be able to: 1. Understand the primary information communication circuits; 2. Able to understand the importance of better codes in communication channels; 3. Help to develop some MDS, and better new codes using the concept of number theory and algebra; 4. Capable of analyzing the capacity of a code based on studied bounds and results.
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### Text Books:

1. Raymond Hill, A First Course in Coding Theory (Oxford Applied Mathematics and Computing Science Series), Clarendon Press, 1986.
2. Ron Roth, Introduction to Coding Theory, Cambridge University Press, 2006.

#### Reference Books:

1. J. H. van Lint, Introduction to Coding Theory, Springer, 1999.
2. M. Shi, A. Alahmadi and P. Sole, Codes and Rings: Theory and Practice. Netherlands: Elsevier Science, 2017.
3. San Ling and Chaoping Xing, Coding Theory: A First Course. Cambridge University Press, 2004.

<b>Course Number</b>	MA6213 (DE)
<b>Course Credit (L-T-P-C)</b>	3-0-0-3
<b>Course Title</b>	Finite Element Analysis
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	In this subject, the students will be trained with the knowledge of mathematical analysis for Finite Element and corresponding computational techniques for solving ODE/PDEs by this approach.
<b>Course Description</b>	Finite Element Analysis is an interdisciplinary subject, focuses on relations between fundamentals of Mathematics and numerical approaches for solving PDEs arising in Engineering modeling.
<b>Course Content</b>	<p>Introduction to Integrable functions and Sobolev Spaces, Piecewise linear basis functions, Polynomial approximations and interpolation errors. Poincare inequality. Variational formulation for elliptic boundary value problems in one and two dimensions. Galerkin orthogonality, Cea's Lemma.</p> <p>Construction of finite element spaces and triangular finite elements. Aubin-Nitsche duality argument; non-conforming elements; computation of finite element solutions and their convergence analysis.</p> <p>Parabolic initial and boundary value problems: Semi-discrete and fully discrete (forward and backward Euler in time) schemes, Convergence analysis. Stiffness matrix. Algorithms and computational experiments by MATLAB.</p>
<b>Learning Outcome</b>	<p>On successful completion of the course, students should be able to:</p> <ol style="list-style-type: none"> <li>1. Know the basic parts of finite element approach</li> <li>2. Error and convergence analysis of the finite element method mathematically</li> <li>3. Write algorithms for solving one and two dimensional ODE/PDEs by using finite element approach</li> <li>4. Know on how to solve applied models by using finite element approach</li> </ol>
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### Text Books:

1. E. Suli and D. F. Mayers, An Introduction to Numerical Analysis, Cambridge Univ. Press, 2003.
2. S. C. Brenner and R. Scott, The Mathematical Theory of Finite Element Methods, Springer, 2008.
3. E. Suli, Lecture Notes on Finite Element Methods for Partial Differential Equations, University of Oxford, 2020.

#### Reference Books:

1. C. Johnson, Numerical solutions of Partial Differential Equations by Finite Element Methods, Cambridge Univ. Press, 2009.
2. Philippe G. Ciarlet, The Finite Element Method for Elliptic Problems, SIAM, 2002



<b>Course Number</b>	MA6214 (DE)
<b>Course Credit (L-T-P-C)</b>	3-0-0-3
<b>Course Title</b>	Introduction to Algebraic Geometry
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	To expose students with the theoretical aspects of curves and prepare a foundation for learning algebraic geometry.
<b>Course Description</b>	This course covers the classical theory of algebraic curves from the point of view of algebraic geometry.
<b>Course Content</b>	Review of ideals and modules, operations with ideals, quotient modules and exact sequences, free modules, Affine space and algebraic sets, ideal of a set of points, The Hilbert basis theorem, irreducible components of algebraic sets, Affine Varieties, Hilbert's Nullstellensatz, coordinate rings, polynomial maps, coordinate changes, rational functions and local rings, local properties of plane curves, tangent lines, intersection number, Divisors on Curves, Degree of a principal divisor, Projective algebraic varieties, projective plane curves, linear systems, Bezout's theorem, Max Noether's fundamental theorem, Zariski topology, varieties, morphism of varieties, rational maps,
<b>Learning Outcome</b>	Students will learn the basic ideas of algebraic geometry such as coordinate ring, function field, affine and projective varieties etc. They will be prepared to take an advance course on algebraic geometry.
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### **Text Books:**

1. Willima Fulton : Algebraic Curves, An Introduction to Algebraic Geometry, Addison-Wesley Publishing Company, Advanced Book Program, 1989
2. S S Abhyankar: Algebraic Geometry For Scientists And Engineers, AMS, 1990
3. David Eisenbud : Commutative Algebra with a view towards Algebraic Geometry, Springer-Verlag New York (1995).

#### **Reference Books:**

1. Justin R Smith: Introduction to Algebraic Geometry, Createspace Independent Pub, Dover reprint, 2014
2. M F Atiyah & I G MacDonald, Introduction to Commutative Algebra, Addison Wesley Publishing Company, 1994

<b>Course Number</b>	MA6215 (DE)
<b>Course Credit</b>	3-0-0-3
<b>Course Title</b>	Operators on Hilbert Spaces
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	The objective of the course is to train student about the properties of operators on Hilbert Spaces.
<b>Course Description</b>	The course is intended to discuss about important mathematical properties of linear transformations between Hilbert spaces to enable students to solve functional equations.
<b>Course Outline</b>	Adjoints of bounded operators on a Hilbert space, Normal, self-adjoint and unitary operators, their spectra and numerical ranges. Compact operators on Hilbert spaces, Spectral theorem for compact self-adjoint operators, Application to Sturm-Liouville Problems.
<b>Learning Outcome</b>	After finishing the course, students will acquire the ability to recognize the fundamental properties of Hilbert spaces and transformations between them.
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

### **Text Books:**

1. J. B. Conway, A Course in Functional Analysis, 2nd ed., Springer, Berlin, 1990.
2. C. Goffman and G. Pedrick, First Course in Functional Analysis, Prentice Hall, 1974.
3. I. Gohberg and S. Goldberg, Basic Operator Theory, Birkhauser, 1981.
4. E. Kreyzig, Introduction to Functional Analysis with Applications, John Wiley & Sons, New York, 1978.
5. B. V. Limaye, Functional Analysis, 2nd ed., New Age International, New Delhi, 1996.
6. M. T. Nair, Functional Analysis: A First Course, PHI Pvt. Ltd, 2004.

<b>Course Number</b>	MA6216 (DE)
<b>Course Credit (L-T-P-C)</b>	3-0-0-3
<b>Course Title</b>	Riemannian Geometry
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	Same as Learning outcome
<b>Course Description</b>	It is a basic introduction to the theory of Riemannian manifolds. This course is fundamental for understanding Einstein theory of General relativity.
<b>Course Content</b>	Riemannian manifolds, Levi-Civita connection, Geodesics; minimising properties of geodesics, Hopf-Rinow theorem, Curvature; sectional curvature, Ricci curvature, scalar curvature, tensors, Jacobi fields, first and second fundamental forms, Hadamard theorem, fundamental group of manifolds of negative curvature, cut locus, injectivity radius, The Sphere theorem.
<b>Learning Outcome</b>	At the end of this course, students should be able to: -compute the curvature of several important examples of Riemannian manifolds of higher dimension. -compute the geodesics on a given Riemannian manifold.
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### **Text Books:**

1. Manfredo P. do Carmo, Riemannian Geometry, Birkhauser (1992)
2. Peter Petersen, Riemannian Geometry, GTM, vol-171, 2<sup>nd</sup> edition, Springer (2006)

#### **Reference Books:**

1. S. Kumaresan, Riemannian Geometry-concepts, examples, and techniques, Techno world (2020)
2. Barrett O. Neill, Semi-Riemannian Geometry with applications to relativity, Academic Press (1983)

<b>Course Number</b>	RM6201
<b>Course Credit (L-T-P-C)</b>	3-1-0-4
<b>Course Title</b>	Research Methodology
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	The objective of the course is to train student about the modelling of scalar and multi-objective nonlinear programming problems and various classical and numerical optimization techniques and algorithms to solve these problems
<b>Course Description</b>	Advanced Optimization Techniques, as a subject for postgraduate and PhD students, provides the knowledge of various models of nonlinear optimization problems and different algorithms to solve such problems with its applications in various problems arising in economics, science and engineering.
<b>Course Content</b>	<p><b>Module I (6 lecture hours) – Research method fundamentals:</b> Definition, characteristics and types, basic research terminology, an overview of research method concepts, research methods vs. method methodology, role of information and communication technology (ICT) in research, Nature and scope of research, information based decision making and source of knowledge. The research process; basic approaches and terminologies used in research. Defining research problem and hypotheses framing to prepare a research plan.</p> <p><b>Module II (5 lecture hours) - Research problem visualization and conceptualization:</b> Significance of literature survey in identification of a research problem from reliable sources and critical review, identifying technical gaps and contemporary challenges from literature review and research databases, development of working hypothesis, defining and formulating the research problems, problem selection, necessity of defining the problem and conceiving the solution approach and methods.</p> <p><b>Module III (5 lecture hours) - Research design and data analysis:</b> Research design – basic principles, need of research design and data classification – primary and secondary, features of good design, important concepts relating to research design, observation and facts, validation methods, observation and collection of data, methods of data collection, sampling methods, data processing and analysis, hypothesis testing, generalization, analysis, reliability, interpretation and presentation.</p> <p><b>Module IV (16 lecture hours) - Qualitative and quantitative analysis:</b> Qualitative Research Plan and designs, Meaning and types of Sampling, Tools of qualitative data Collection; observation depth Interview, focus group discussion, Data editing, processing &amp; categorization, qualitative data analysis, Fundamentals of statistical methods, parametric and nonparametric techniques, test of significance, variables, conjecture, hypothesis, measurement, types of data and scales, sample and sampling techniques, probability and distributions, hypothesis testing, level of significance and confidence interval, t-test, ANOVA, correlation, regression analysis, error analysis, research data analysis and evaluation using software tools (e.g.: MS Excel, SPSS, Statistical, R, etc.).</p> <p><b>Module V (10 lecture hours) – Principled research:</b> Ethics in research and Ethical dilemma, affiliation and conflict of interest; Publishing and sharing research, Plagiarism and its fallout (case studies), Internet</p>

	research ethics, data protection and intellectual property rights (IPR) – patent survey, patentability, patent laws and IPR filing process.
<b>Learning Outcome</b>	<p>On successful completion of the course, students should be able to:</p> <ol style="list-style-type: none"> <li>1. Understand the terminology and basic concepts of various kinds of nonlinear optimization problems.</li> <li>2. Develop the understanding about different solution methods to solve nonlinear Programming problems.</li> <li>3. Apply and differentiate the need and importance of various algorithms to solve scalar and multi-objective optimization problems.</li> <li>4. Employ programming languages like MATLAB/Python to solve nonlinear programming problems.</li> <li>5. Model and solve several problems arising in science and engineering as a nonlinear optimization problem.</li> </ol>
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### **Textbooks & Reference Books:**

1. C. R. Kothari, Research methodology: Methods and Techniques, 3rd Edn., New age International 2014.
2. Mark N K. Saunders, Adrian Thornhill, Phkip Lewis, “Research Methods for Studies, 3/c Pearson Education, 2010.
3. K.N. Krishnaswamy, apa iyer, siva kumar, m. Mathirajan, “Management Research Methodology”, Pearson Education, 2010.
4. Ranjit Kumar; “Research Methodology: A Step by Step Guide for Beginners; 2/e; Pearson Education, 2010.
5. Suresh C. Sinha, Anil K. Dhiman, ess ess, 2006 “Research Methodology” Panner Selvam.R. “Research Methodology”, Prentice Hall of India, New Delhi, 2004.
6. C.G. Thomas, Research methodology and scientific writing, Ane books, Delhi, 2015.
7. H. J. Ader and G. J. Mellenbergh, Research Methodology in the Social, Behavioural and Life Sciences Designs, Models and Methods, 3rd Edn., Sage Publications, London, 2000.

**Interdisciplinary Elective (IDE) Course for M. Tech. (Available to students other than Math)**

<b>Sl. No.</b>	<b>Subject Code</b>	<b>IDE</b>	<b>L</b>	<b>T</b>	<b>P</b>	<b>C</b>
1.	MA6109	Mathematical Modeling	3	0	0	3

<b>Course Number</b>	MA6109 (IDE)
<b>Course Credit (L-T-P-C)</b>	3-0-0-3
<b>Course Title</b>	Mathematical Modeling
<b>Learning Mode</b>	Lectures
<b>Learning Objectives</b>	To understand the importance of mathematics as tool in different areas. To understand the relation of physical world and its corresponding representation into mathematical terms. To understand systematic process of modeling a system. To expose students to the differential equations and their qualitative behavior and application in mathematical modeling. To learn through some of the examples of mathematical models in different areas.
<b>Course Description</b>	This course is meant to expose the candidate to basic philosophy of mathematical modeling and then apply it to various systems and analyse these models.
<b>Course Content</b>	<p>Stability of scalar nonlinear differential equations; Linear and nonlinear stability of system of differential equations; Lyapunov Stability, Examples.</p> <p>Introduction to modeling; Elementary mathematical models and General modeling ideas; General utility of Mathematical models, Role of mathematics in problem solving; Concepts of mathematical modeling; System approach; formulation, Analyses of models; Pitfalls in modeling.</p> <p>Illustrations of models with their analysis in Population dynamics, Traffic Flow, Social interactions, Viral infections, Epidemics, Finance, Economics, Management, etc. (The choice and nature of models selected may be changed with mutual interest of lecturer and students.)</p> <p>Introduction to probabilistic models and their analysis. Introduction to stochastic differential equations and application in modeling.</p>
<b>Learning Outcome</b>	Students will be able to apply the mathematical knowledge on a physical system and obtain a mathematical model, analyse it and interpret it in terms of the physical world
<b>Assessment Method</b>	Quiz /Assignment/ Project / MSE / ESE

#### **Text Books:**

1. D. N. P. Murthy, N. W. Page, Ervin Y. Rodin, Mathematical modelling: a tool for problem solving in engineering, physical, biological, and social sciences, Pergamon Press, 1990.
2. W. E. Boyce and R.C. DiPrima, Elementary Equations and Boundary Value Problems, 7th Edition, Wiley, 2001.

#### **Reference Books:**

1. J. D. Murray, Mathematical Biology, Vol I, 3rd Ed, Springer, 2003.
2. Wei-Bin Zhang, Differential equations, bifurcations, and chaos in economics, Series on Advances in Mathematics for Applied Sciences, Vol 68, World Scientific, 2005.
3. M. Kot, Elements of Mathematical Ecology, Cambridge University Press, 2012.