Anekant Education Society's

Tuljaram Chaturchand College of Arts, Science & Commerce, Baramati

(*Empowered Autonomous*)

Three/Four Year Honours/Honours with Research B.Sc. Degree Program in Mathematics

(Faculty of Science)

CBCS Syllabus

T.Y.B.Sc. (Mathematics)

For Department of Mathematics

NEP-1.0

Choice Based Credit System Syllabus

(2023 Pattern)

(As Per NEP-2020)

To be implemented from Academic Year 2025-26

Title of the Programme: B.Sc. (Mathematics)

Preamble

AES's Tuljaram Chaturchand College has made the decision to change the syllabus of across various faculties from June, 2023 by incorporating the guidelines and provisions outlined in the National Education Policy (NEP), 2020. The NEP envisions making education more holistic and effective and to lay emphasis on the integration of general (academic) education, vocational education and experiential learning. The NEP introduces holistic and multidisciplinary education that would help to develop intellectual, scientific, social, physical, emotional, ethical and moral capacities of the students. The NEP 2020 envisages flexible curricular structures and learning based outcome approach for the development of the students. By establishing a nationally accepted and internationally comparable credit structure and courses framework, the NEP 2020 aims to promote educational excellence, facilitate seamless academic mobility, and enhance the global competitiveness of Indian students. It fosters a system where educational achievements can be recognized and valued not only within the country but also in the international arena, expanding opportunities and opening doors for students to pursue their aspirations on a global scale.

In response to the rapid advancements in science and technology and the evolving approaches in various domains of Mathematics and related subjects, the Board of Studies in Mathematics at Tuljaram Chaturchand College, Baramati - Pune, has developed the curriculum for the fifth semester of T.Y.B.Sc. (Mathematics), which goes beyond traditional academic boundaries. The syllabus is aligned with the NEP 2020 guidelines to ensure that students receive an education that prepares them for the challenges and opportunities of the 21st century. This syllabus has been designed under the framework of the Choice Based Credit System (CBCS), taking into consideration the guidelines set forth by the National Education Policy (NEP) 2020, LOCF (UGC), NCrF, NHEQF, Prof. R. D. Kulkarni's Report, Government of Maharashtra's General Resolution dated 20th April and 16th May 2023, and 13th March, 2024 and Circular of SPPU, Pune dated 31st May 2023.

A Mathematics degree equips students with the knowledge and skills necessary for a diverse range of fulfilling career paths. Graduates in Mathematics find opportunities in various fields, including Financial Planner, Market Research Analyst, Data Scientist, teaching, Insurance underwriter, operations research analyst, software developer, and many other domains. After graduating with a degree in mathematics, students can embark on a multitude of rewarding and diverse career paths. The analytical and problem-solving skills honed during their studies equip them with a strong foundation for success in various fields. Many graduates choose to pursue careers in academia and research, where they can contribute to the advancement of mathematical knowledge through teaching, publishing papers, and conducting ground breaking research. Others may opt for careers in the financial sector, such as investment banking or actuarial science, utilizing their expertise in mathematical modelling and statistical analysis to make informed decisions and manage risks. Additionally, the field of data science offers abundant opportunities for mathematics graduates, as they possess the ability to extract meaningful insights from complex data sets and develop algorithms that drive innovation in industries like technology, healthcare, and marketing. Moreover, mathematics graduates can find fulfilling careers in engineering, cryptography, software development, and operations research, to name just a few areas where their mathematical skills are highly sought after. Overall, a degree in mathematics opens doors to a wide range of intellectually stimulating and financially rewarding professions, allowing graduates to make significant contributions to society and thrive in a rapidly evolving world.

Overall, revising the Mathematics syllabus in accordance with the NEP 2020 ensures that students receive an education that is relevant, comprehensive, and prepares them to navigate the dynamic and interconnected world of today. It equips them with the knowledge, skills, and competencies needed to contribute meaningfully to society and pursue their academic and professional goals in a rapidly changing global landscape.

Credit Distribution Structure for T.Y.B.Sc. as per NEP 2020 (for NEP 1.0 2023 Pattern)

Level	Sem.	Major		Minor	OE	VSC, SEC, (VSEC)	AEC, VEC, IKS	OJT, FP, CEP, CC, RP	Cum. Cr/Sem	Degree /Cum. Cr.
		Mandatory	**Electives**							
5.5	V	**MAT-301-MJM:** Metrics Spaces and Introduction to Topology **(2 Credit)** **MAT-302-MJM:** Fundamentals of Mathematical Analysis **(2 Credit)** **MAT-303-MJM:** Introduction to Group Theory **(2 Credit)** **MAT-304-MJM:** Elementary Number Theory **(2 Credit)** **MAT-305-MJM:** Practical on Analysis and Algebra – I **(2 Credit)**	**MAT-306-MJE(A):** Partial Differential Equations **(2 Credit)** **MAT-306-MJE(B):** Fundamentals of Graph Theory **(2 Credit)** **MAT-306-MJE(C):** Introduction to Numerical Analysis **(2 Credit)** **(Any Two)**	**MAT-311-MJM:** Basic Abstract Algebra **(2 Credit)** **MAT-312-MJM:** Practical based on Numerical Methods **(2 Credit)**	--	**MAT-321-VSC:** Practical Applications of LaTeX in Mathematical Documentation **(2 Credit)**	--	FP **(2 Credit)**	22	UG Degree 44 credits
	VI	**MAT-351-MJM:** Basic Course in Complex Analysis **(2 Credit)** **MAT-352-MJM:** Introduction to Ring Theory **(2 Credit)** **MAT-353-MJM:** Riemann Integration and Series of Functions **(2 Credit)** **MAT-354-MJM:** Lebesgue Integration **(2 Credit)** **MAT-355-MJM:** Practical on Analysis and Algebra – II **(2 Credit)**	**MAT-356-MJE(A):** Optimization Techniques **(2 Credit)** **MAT-356-MJE(B):** Computational Geometry **(2 Credit)** **MAT-356-MJE(C):** Introduction to Lattice Theory **(2 Credit)** **(Any Two)**	**MAT-311-MJM:** Mathematical Analysis **(2 Credit)** **MAT-312-MJM:** Practical based on Lattice Theory and Fourier Series **(2 Credit)**	--	--	--	OJT **(4 Credit)**	22	
	Cum Cr.	**20**	**08**	**08**	**--**	**02**	**--**	**06**	**44**	

Anekant Education Society's

Tuljaram Chaturchand College of Arts, Science and Commerce, Baramati

(Empowered Autonomous)

NEP-1.0

Course Structure for F.Y.B.Sc. (2023 Pattern as per NEP-2020)

Sem	Course Type	Course Code	Course Title	Theory / Practical	Credits
I	Major Mandatory	MAT-101-MJM	Algebra	Theory	02
	Major Mandatory	MAT-102-MJM	Calculus	Theory	02
	Major Mandatory	MAT-103-MJM	Mathematics Practical I	Practical	02
	Open Elective (OE)	MAT-116-OE	Basic Mathematics I	Theory	02
	Open Elective (OE)	MAT-117-OE	Applied Mathematics I	Practical	02
	Vocational Skill Course (VSC)	MAT-121-VSC	Logical Methods	Theory	02
	Skill Enhancement Course (SEC)	MAT-126-SEC	Scilab and Maxima Software I	Practical	02
	Ability Enhancement Course (AEC)	ENG-131-AEC	Functional English-I	Theory	02
	Value Education Course (VEC)	MAT-135-VEC	Mathematics for Environmental Science	Theory	02
	Indian Knowledge System (IKS)	MAT-137-IKS	Vedic Mathematics	Theory	02
	Co-curricular Course (CC)	--	To be selected from the Basket	Theory	02
				Total Credits Semester-I	**22**
II	Major Mandatory	MAT-151-MJM	Geometry	Theory	02
	Major Mandatory	MAT-152-MJM	Calculus and Differential Equations	Theory	02
	Major Mandatory	MAT-153-MJM	Mathematics Practical II	Practical	02
	Minor	MAT-161-MN	Fundamentals of Mathematics	Theory	02
	Open Elective (OE)	MAT-166-OE	Basic Mathematics II	Theory	02
	Open Elective (OE)	MAT-167-OE	Applied Mathematics II	Practical	02
	Vocational Skill Course (VSC)	MAT-171-VSC	Geogebra Software	Practical	02
	Skill Enhancement Course (SEC)	MAT-176-SEC	Scilab and Maxima Software II	Practical	02
	Ability Enhancement Course (AEC)	ENG-181-AEC	Functional English-II	Theory	02
	Value Education Course (VEC)	MAT-185-VEC	Mathematical Solutions for Environmental Challenges	Theory	02
	Co-curricular Course (CC)	--	To be selected from the Basket	Theory	02
				Total Credits Semester-II	**22**
				Cumulative Credits Semester I + Semester II	**44**

Course Structure for S.Y.B.Sc. Mathematics (2023 Pattern as per NEP-2020)

Sem	Course Type	Course Code	Course Title	Theory / Practical	Credits
III	Major Mandatory	MAT-201-MJM	Calculus of Several Variables	Theory	02
	Major Mandatory	MAT-202-MJM	Laplace Transform & Fourier Series	Theory	02
	Major Mandatory	MAT-203-MJM	Ordinary Differential Equations	Theory	02
	Major Mandatory	MAT-204-MJM	Mathematics Practical III	Practical	02
	Minor	MAT-211-MN	Foundations of Linear Algebra	Theory	02
	Minor	MAT-212-MN	Practical based on Ordinary Differential Equations	Practical	02
	Open Elective (OE)	MAT-216-OE	Intermediate Mathematics	Theory	02
	Vocational Skill Course (VSC)	MAT-221-VSC	Financial Mathematics	Theory	02
	Ability Enhancement Course (AEC)	MAR-231-AEC HIN-231-AEC SAN-231-AEC	भाषिक उपयोजन व लेखन कौशल्ये हिंदी भाषा: श्रुजन कौशल प्राथमिक संभाषणकौशल्यम्	Theory	02
	Field Project (FP)	MAT-235-FP	Field Project	Practical	02
	Co-curricular Course (CC)	YOG/PES/CUL /NSS/NCC-239-CC	To be selected from the Basket	Theory	02
	Generic IKS Course (IKS)	GEN-245-IKS		Theory	02
				Total Credits Semester-III	**24**
IV	Major Mandatory	MAT-251-MJM	Vector Calculus	Theory	02
	Major Mandatory	MAT-252-MJM	Linear Algebra	Theory	02
	Major Mandatory	MAT-253-MJM	Operations Research	Theory	02
	Major Mandatory	MAT-254-MJM	Mathematics Practical IV	Practical	02
	Minor	MAT-261-MN	Multivariable Calculus	Theory	02
	Minor	MAT-262-MN	Practical based on Partial Differential Equations	Practical	02
	Open Elective (OE)	MAT-266-OE	Mathematical Methods	Practical	02
	Skill Enhancement Course (SEC)	MAT-276-SEC	Geogebra Software	Practical	02
	Ability Enhancement Course (AEC)	MAR-281-AEC HIN-281-AEC SAN-281-AEC	लेखन निर्मिती व परीक्षण कौशल्ये हिंदी भाषा: संप्रेषण कौशल प्रगत संभाषणकौशल्यम्	Theory	02
	Community Engagement Project (CEP)	MAT-285-CEP	Community Engagement Project	Practical	02
	Co-curricular Course (CC)	YOG/PES/CUL /NSS/NCC-289-CC	To be selected from the Basket	Theory	02
				Total Credits Semester-IV	**22**
				Cumulative Credits Semester III + Semester IV	**46**

Course Structure for T.Y.B.Sc. Mathematics (2023 Pattern as per NEP-2020)

<table>
<tr><th>Sem</th><th>Course Type</th><th>Course Code</th><th>Course Title</th><th>Theory / Practical</th><th>Credits</th></tr>
<tr><td rowspan="13">V</td><td>Major Mandatory</td><td>MAT-301-MJM</td><td>Metric Spaces and Introduction to Topology</td><td>Theory</td><td>02</td></tr>
<tr><td>Major Mandatory</td><td>MAT-302-MJM</td><td>Fundamentals of Mathematical Analysis</td><td>Theory</td><td>02</td></tr>
<tr><td>Major Mandatory</td><td>MAT-303-MJM</td><td>Introduction to Group Theory</td><td>Theory</td><td>02</td></tr>
<tr><td>Major Mandatory</td><td>MAT-304-MJM</td><td>Elementary Number Theory</td><td>Theory</td><td>02</td></tr>
<tr><td>Major Mandatory</td><td>MAT-305-MJM</td><td>Practical on Analysis and Algebra – I</td><td>Practical</td><td>02</td></tr>
<tr><td rowspan="3">Major Elective</td><td>MAT-306-MJE (A)</td><td>Partial Differential Equations</td><td rowspan="3">Theory (Any Two)</td><td rowspan="3">02</td></tr>
<tr><td>MAT-306-MJE (B)</td><td>Fundamentals of Graph Theory</td></tr>
<tr><td>MAT-306-MJE (C)</td><td>Introduction to Numerical Analysis</td></tr>
<tr><td>Minor</td><td>MAT-311-MN</td><td>Basic Abstract Algebra</td><td>Theory</td><td>02</td></tr>
<tr><td>Minor</td><td>MAT-312-MN</td><td>Practical based on Numerical Methods</td><td>Practical</td><td>02</td></tr>
<tr><td>Vocational Skill Course (VSC)</td><td>MAT-321-VSC</td><td>Practical Applications of LaTeX in Mathematical Documentation</td><td>Practical</td><td>02</td></tr>
<tr><td>Field Project (FP)</td><td>MAT-335-FP</td><td>Field Project</td><td>Practical</td><td>02</td></tr>
<tr><td colspan="4" align="right">Total Credits Semester-V</td><td>22</td></tr>
<tr><td rowspan="12">VI</td><td>Major Mandatory</td><td>MAT-351-MJM</td><td>Basic Course in Complex Analysis</td><td>Theory</td><td>02</td></tr>
<tr><td>Major Mandatory</td><td>MAT-352-MJM</td><td>Introduction to Ring Theory</td><td>Theory</td><td>02</td></tr>
<tr><td>Major Mandatory</td><td>MAT-353-MJM</td><td>Riemann Integration and Series of Functions</td><td>Theory</td><td>02</td></tr>
<tr><td>Major Mandatory</td><td>MAT-354-MJM</td><td>Lebesgue Integration</td><td>Theory</td><td>02</td></tr>
<tr><td>Major Mandatory</td><td>MAT-355-MJM</td><td>Practical on Analysis and Algebra – II</td><td>Practical</td><td>02</td></tr>
<tr><td rowspan="3">Major Elective</td><td>MAT-356-MJE (A)</td><td>Optimization Techniques</td><td rowspan="3">Theory (Any Two)</td><td rowspan="3">02</td></tr>
<tr><td>MAT-356-MJE (B)</td><td>Computational Geometry</td></tr>
<tr><td>MAT-356-MJE (C)</td><td>Introduction to Lattice Theory</td></tr>
<tr><td>Minor</td><td>MAT-361-MN</td><td>Mathematical Analysis</td><td>Theory</td><td>02</td></tr>
<tr><td>Minor</td><td>MAT-362-MN</td><td>Practical based on Laplace Transforms and Fourier Series</td><td>Practical</td><td>02</td></tr>
<tr><td>On Job Training (OJT)</td><td>MAT-385-OJT</td><td>On Job Training</td><td>Practical</td><td>04</td></tr>
<tr><td colspan="4" align="right">Total Credits Semester-VI</td><td>22</td></tr>
<tr><td colspan="5" align="right">Cumulative Credits Semester V + Semester VI</td><td>44</td></tr>
</table>

Programme Specific Outcomes (PSOs)

PSO 1-Proficiency in Mathematical Concepts: Graduates will have a deep understanding of fundamental mathematical concepts and theories across various branches of mathematics, including calculus, algebra, geometry, probability, and statistics.

PSO 2-Problem-Solving Skills: Graduates will possess strong problem-solving skills and the ability to apply mathematical principles to real-world situations. They can analyze complex problems, develop logical reasoning, and devise creative strategies to find solutions.

PSO 3-Mathematical Modeling: Graduates will be proficient in mathematical modeling, which involves using mathematical techniques to describe and analyze real-world phenomena. They can formulate and solve mathematical models to address problems in diverse fields, including physics, economics, engineering, and social sciences.

PSO4-Computational and Analytical Skills: Graduates will be skilled in using computational tools and software, such as programming languages, statistical software, and mathematical modeling software. They can leverage these tools to perform numerical analysis, data visualization, and simulations.

PSO 5-Communication and Presentation: Graduates will possess effective communication skills, both written and oral, to convey complex mathematical ideas and results to both technical and non-technical audiences. They can present mathematical arguments, proofs, and findings in a clear and concise manner.

PSO 6-Research and Inquiry: Graduates will have the ability to engage in mathematical research and inquiry. They can critically evaluate existing mathematical theories, develop new mathematical models, and contribute to the advancement of mathematical knowledge through independent research or collaborative projects.

PSO 7-Interdisciplinary Collaboration: Graduates will be adept at collaborating with professionals from other disciplines, such as scientists, engineers, economists, and computer scientists. They can effectively communicate and work in multidisciplinary teams to solve complex problems that require mathematical expertise.

PSO 8-Lifelong Learning: Graduates will have developed a strong foundation for lifelong learning in mathematics. They will have the skills to stay abreast of new developments in the field, adapt to emerging technologies and methodologies, and continue their professional growth through self-directed study or advanced academic pursuits.

PSO 9-Advanced Mathematical Techniques: Graduates will have a command of advanced mathematical techniques, such as differential equations, mathematical analysis, linear algebra, number theory, and optimization. They can apply these advanced mathematical tools to solve complex problems and contribute to specialized areas of research.

PSO 10-Mathematical Software Development: Graduates will possess programming skills and the ability to develop mathematical software or algorithms. They can design, implement, and optimize software applications that facilitate mathematical calculations, simulations, data analysis, and modeling.

PSO 11-Mathematical Education and Teaching: Graduates interested in pursuing a career in education will have the necessary skills to teach mathematics at various levels. They can design and deliver effective lessons, develop curriculum materials, and assess student progress in mathematics. They can also inspire and motivate students to develop an appreciation for the subject.

PSO 12-Mathematical Finance and Risk Analysis: Graduates with an interest in finance and economics will have specialized knowledge in mathematical finance and risk analysis. They can apply mathematical models, stochastic calculus, and statistical methods to analyze financial markets, manage investment portfolios, assess risk, and make informed financial decisions.

CBCS Syllabus as per NEP 2020 for T.Y.B.Sc. Mathematics (2023 Pattern)

Name of the Programme	**:** B.Sc. Mathematics
Program Code	**:** USMT
Class	**:** T.Y.B.Sc.
Semester	**:** V
Course Type	**:** Major Mandatory
Course Name	**:** Metric Spaces and Introduction to Topology
Course Code	**:** MAT-301-MJM
No. of Teaching Hours	**:** 30
No. of Credits	**:** 2

Course Objectives:

1. To develop a rigorous understanding of metric spaces as a foundation for advanced analysis.
2. To learn to define and manipulate distances in metric spaces.
3. To grasp the concepts of convergence and completeness in metric spaces.
4. To explore the topological properties of metric spaces, including open and closed sets, subspaces, and separation axioms.
5. To analyze continuity and its variations (uniform continuity, homeomorphism) in the context of metric spaces.
6. To investigate connectedness and its different forms (connected, locally connected, arcwise connected) in metric spaces.
7. To introduce the concept of compactness in metric spaces and its applications**.**

Course Outcomes:

CO1: Students will be able to define a metric space and provide examples of common metric spaces.
CO2: Students will be able to prove statements about distances in metric spaces and use them to solve problems.
CO3: Students will be able to determine the convergence of sequences in a metric space and identify Cauchy sequences.
CO4: Students will be able to explain the concept of completeness and demonstrate its importance in metric spaces.
CO5: Students will be able to define open and closed sets in a metric space and prove basic theorems related to them.
CO6: Students will be able to analyze the continuity of functions between metric spaces and apply extension theorems.
CO7: Students will be able to identify connected and compact sets in metric spaces and prove their key properties.

Topics and Learning Points

	Teaching Hours
Unit 1: Metric Spaces	**07**
1.1 Introduction: The Euclidean spaces, Balls and Bounded sets	
1.2 Convergence in Metric Spaces	
1.3 Normed Linear Spaces	
1.4 Sequence Spaces	
Unit 2: Topology	**07**
2.1 Open and Closed Sets	
2.2 Limit Points and Isolated Points	
2.3 Closure and Boundaries	
2.4 Limits and Continuity	
Unit 3: Completeness	**06**
3.1 Introduction	
3.2 Banach Contraction Principle	
3.3 Characterization of Completeness	
3.4 Completion of Metric Spaces	
Unit 4: Compactness	**05**
4.1 Compact and Closed Sets	
4.2 Characterization of Compact Sets	
4.3 Continuity and Compactness	
4.4 Lipschitz Continuity	
Unit 5: Connectedness	**05**
5.1 Path Connectedness	
5.2 Connected Sets	
5.3 Components	

Text Book:

Surinder Pal Singh Kainth, *A Comprehensive Textbook on Metric Spaces*, Springer.

Unit 1: Chapter 2, **Unit 2:** Chapter 3, **Unit 3:** Chapter 4,
Unit 4: Chapter 5, **Unit 5:** Chapter 6.

Reference Books:

1. Micheal O'Searcoid, *Metric Spaces*, Springer.
2. Satish Shirali and Harkrishan L. Vasudeva, *Metric Spaces*, Springer
3. James R. Munkres, *Topology*, Pearson.
4. Pawan K. Jain and Khalil Ahmad, *Metric Spaces*, Narosa Publishing House.
5. Richard R. Goldberg, *Methods of Real Analysis*, Oxford & IBH Publishing Co. Pvt. Ltd.

CO-PO Mapping

Weightage: 1 – weak or low relation, 2 – moderate or partial relation, 3 – strong or direct relation

Programme Outcomes	Course Outcomes						
	CO1	CO2	CO3	CO4	CO5	CO6	CO7
PO01	3	3	3	3	3	3	3
PO02	2	3	3	3	3	3	3
PO03	1	1	2	2	2	2	2
PO04	2	3	3	3	3	3	3
PO05	2	3	3	3	3	3	3
PO06	1	2	2	2	2	2	2
PO07	1	2	3	3	3	3	3
PO08	2	3	3	3	3	3	3
PO09	1	2	2	2	2	2	2
PO10	1	1	1	1	1	1	1
PO11	1	1	1	1	1	1	1
PO12	1	2	2	2	2	2	2
PO13	1	1	1	1	1	1	1

Justification for the mapping

PO1: ***Comprehensive knowledge and understanding*** - CO1 to CO7 have a strong relation as the course provides a thorough understanding of metric spaces, including their properties, sequences, completeness, and continuity.

PO2: ***Practical, professional, and procedural knowledge*** - CO1 has a moderate relation as defining metric spaces is more theoretical and CO2 to CO7 have a strong relation since proving statements, convergence, and completeness are essential for real-world applications and advanced mathematical studies.

PO3: ***Entrepreneurial mindset and knowledge*** **-** CO1 has a weak relation as basic definitions have limited entrepreneurial applications and CO3 to CO7 have a moderate relation since understanding metric spaces can help in algorithm design, data science, and innovation in mathematical fields.

PO4: ***Specialized skills and competencies*** - CO1 has a moderate relation as understanding metric spaces is fundamental but not an advanced skill itself and CO2 to CO7 have a strong relation as they require specialized skills like proving theorems, analyzing continuity, and applying extension theorems.

PO5: ***Capacity for Application, Problem-Solving, and Analytical Reasoning*** - CO1 has a moderate relation because understanding definitions aids problem-solving and CO2 to CO7 have a strong relation as proving convergence, continuity, and compactness are essential for mathematical problem-solving.

PO6: ***Communication skills and collaboration*** - CO1 has a weak relation since defining metric spaces does not require communication skills and CO2 to CO7 have a moderate relation as writing proofs and discussing mathematical ideas require clear communication and collaboration.

PO7: ***Research-related skills*** - CO1 has a weak relation since defining metric spaces does not directly contribute to research and CO2 has a moderate relation, while CO3 to CO7 have a strong relation as proving results, analyzing continuity, and working with compactness are essential for mathematical research.

PO8: ***Learning how to learn skills*** - CO1 has a moderate relation since it introduces foundational concepts and CO2 to CO7 have a strong relation as proving theorems and working with abstract mathematical structures enhance self-learning and deeper exploration.
PO9: ***Digital and technological skills*** - CO1 has a weak relation as basic definitions have minimal computational applications and CO2 to CO7 have a moderate relation since these concepts are useful in computational mathematics, numerical analysis, and algorithm design.
PO10: ***Multicultural competence, inclusive spirit, and empathy*** - CO1 to CO7 have a weak relation as metric space concepts are purely mathematical and do not directly involve multicultural competence or empathy.
PO11: ***Value inculcation and environmental awareness*** - CO1 to CO7 have a weak relation as metric spaces do not directly address ethical, moral, or environmental concerns.
PO12: ***Autonomy, responsibility, and accountability*** - CO1 has a weak relation as defining metric spaces does not require autonomy and CO2 to CO7 have a moderate relation since proving theorems and solving abstract problems require independent learning and responsibility.
PO13: ***Community engagement and service*** - CO1 to CO7 have a weak relation as metric space theory does not directly contribute to community engagement or service.

CBCS Syllabus as per NEP 2020 for T.Y.B.Sc. Mathematics (2023 Pattern)

Name of the Programme	: B.Sc. Mathematics
Program Code	: USMT
Class	: T.Y.B.Sc.
Semester	: V
Course Type	: Major Mandatory
Course Name	: Fundamentals of Mathematical Analysis
Course Code	: MAT-302-MJM
No. of Teaching Hours	: 30
No. of Credits	: 2

Course Objectives:

1. To understand the fundamental concepts of sets and functions, including operations on sets and different types of functions, such as real-valued functions.
2. To analyze the properties of real numbers, their significance in mathematical analysis, and the concept of least upper bound.
3. To examine set theory concepts, including equivalence and countability, and their applications in real analysis.
4. To understand and analyze sequences of real numbers, focusing on subsequences, convergence, and monotonicity.
5. To investigate bounded sequences and sequence operations, exploring their properties and implications in real analysis.
6. To explore advanced sequence concepts, such as limit superior and limit inferior, and their role in sequence analysis.
7. To understand the significance of Cauchy sequences, their properties, and their applications in real analysis.

Course Outcomes:

CO1: Students will be able to demonstrate proficiency in performing operations on sets and understanding their properties.

CO2: Students will be able to apply knowledge of functions to solve problems involving real-valued functions.

CO3: Students will be able to analyze real numbers and their properties in the context of mathematical analysis.

CO4: Students will be able to determine the equivalence and countability of sets and their relevance in mathematical analysis.

CO5: Students will be able to utilize the concept of least upper bound to analyze real numbers and sequences.

CO6: Students will be able to evaluate the convergence and monotonicity of sequences and their implications.

CO7: Students will be able to demonstrate proficiency in applying various tests for convergence and absolute convergence of series, including the class l^2.

Topics and Learning Points

	Teaching Hours
Unit 1: Sets and functions	**07**
1.1 Sets and operations on sets	
1.2 Functions and Real valued functions	
1.3 Equivalence and countability	
1.4 Real numbers	
1.5 Least upper bound	
Unit 2: Introduction to Sequences	**06**
2.1 Sequence and subsequence	
2.2 Convergence of sequence	
2.3 Bounded and monotone sequences	
Unit 3: Advanced concepts in Sequences	**06**
3.1 Operations on sequences	
3.2 Limit superior and limit inferior	
3.3 Cauchy sequences	
Unit 4: Fundamentals of Series	**05**
4.1 Convergence of series	
4.2 Series with nonnegative terms	
4.3 Alternating series	
Unit 5: Advanced topics in Series	**06**
5.1 Conditional and absolute convergence	
5.2 Tests for absolute convergence of series	
5.3 The class l^2	

Text Book:

Richard R. Goldberg, *Methods of Real Analysis*, Oxford & IBH Publishing Co. Pvt. Ltd., Indian Edition.
Unit 1: Sections 1.1 to 1.7, **Unit 2:** Sections 2.1 to 2.6, **Unit 3:** Sections 2.7 to 2.10, **Unit 4:** Sections 3.1 to 3.3, **Unit 5:** Sections 3.4, 3.6, 3.7 & 3.10.

Reference Books:

1. Ajit Kumar and S. Kumaresan, *A Basic Course in Real Analysis*, CRC Press, Second Indian Reprint 2015.
2. D. Somasundaram and B. Choudhary, *A first course in Mathematical Analysis*, Narosa Publishing House, 1997.
3. Robert G. Bartle and Donald Sherbert, *Introduction to Real Analysis*, John Wiley and Sons, 3rd Edition.
4. Shantinarayan and Mittal, *A course of Mathematical Analysis*, S. Chand and Co., Revised Edition (2002).
5. S. C. Malik and Savita Arora, *Mathematical Analysis*, New Age International Publications, 3rd Edition (2008).

CO-PO Mapping

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PO01	3	3	3	3	3	3	3
PO02	2	3	3	2	3	3	3
PO03	1	1	1	1	1	1	1
PO04	2	3	3	2	3	3	3
PO05	3	3	3	3	3	3	3
PO06	1	2	2	1	2	2	2
PO07	2	2	3	2	3	3	3
PO08	3	3	3	3	3	3	3
PO09	1	2	2	1	2	2	2
PO10	1	1	1	1	1	1	1
PO11	1	1	1	1	1	1	1
PO12	2	2	3	2	3	3	3
PO13	1	1	1	1	1	1	1

Justification for the mapping

PO1: ***Comprehensive knowledge and understanding*** - Understanding sets, functions, real numbers, sequences, and series is fundamental to mathematical analysis. Each CO contributes to deep theoretical knowledge.

PO2: ***Practical, professional, and procedural knowledge*** - CO2, CO3, CO5, CO6, and CO7 are rated 3 as they involve applying mathematical concepts to problem-solving. CO1 and CO4 have a 2 rating since they emphasize foundational understanding rather than direct application.

PO3: ***Entrepreneurial mindset and knowledge*** **-** The course is theoretical in nature, with limited direct application to entrepreneurial skills.

PO4: ***Specialized skills and competencies*** - CO2, CO3, CO5, CO6, and CO7 are rated 3 because they develop analytical skills for mathematical reasoning. CO1 and CO4 are rated 2 as they contribute to specialized skills but in a limited manner.

PO5: ***Capacity for Application, Problem-Solving, and Analytical Reasoning*** - Each CO involves problem-solving and analytical reasoning, making this a direct and strong connection.

PO6: ***Communication skills and collaboration*** - CO2, CO3, CO5, CO6, and CO7 are rated 2 as they involve discussing and presenting mathematical ideas. CO1 and CO4 are rated 1 due to their theoretical nature.

PO7: ***Research-related skills*** - CO3, CO5, CO6, and CO7 are rated 3 since they provide a strong foundation for research in mathematical analysis. CO1, CO2, and CO4 are rated 2 as they contribute but not as strongly.

PO8: ***Learning how to learn skills*** - Mastering mathematical concepts requires independent learning, critical thinking, and self-improvement, making all COs highly relevant.

PO9: ***Digital and technological skills*** - CO2, CO3, CO5, CO6, and CO7 are rated 2 as technology can aid in problem-solving. CO1 and CO4 are rated 1 as they do not directly involve technology.

PO10: ***Multicultural competence, inclusive spirit, and empathy*** - The course does not explicitly contribute to multicultural competence or inclusivity.

PO11: ***Value inculcation and environmental awareness*** - The course does not have a direct link to ethical or environmental considerations.

PO12: ***Autonomy, responsibility, and accountability*** - CO3, CO5, CO6, and CO7 are rated 3 since they require independent critical thinking. CO1, CO2, and CO4 are rated 2 due to their theoretical aspects.
PO13: ***Community engagement and service*** - The course is theoretical and does not directly contribute to community service.

CBCS Syllabus as per NEP 2020 for T.Y.B.Sc. Mathematics (2023 Pattern)

Name of the Programme : B.Sc. Mathematics
Program Code : USMT
Class : T.Y.B.Sc.
Semester : V
Course Type : Major Mandatory
Course Name : Introduction to Group Theory
Course Code : MAT-303-MJM
No. of Teaching Hours : 30
No. of Credits : 2

Course Objectives:

1. To Introduce students to the fundamental concept of abstract algebra and the notion of mathematical structures called groups.
2. To develop problem-solving skills through the exploration of group theory concepts and the solution of theoretical and practical problems.
3. To study various operations on groups, including multiplication, addition, and composition, and understanding how these operations interact with group properties.
4. To understand the notion of group isomorphisms, Caley's theorem and their role in establishing equivalences between different groups.
5. To explore the concepts of subgroups and cosets within groups, and understanding their significance in group theory.
6. To enhance students' ability to formulate rigorous mathematical arguments and proofs related to group theory concepts and theorems.
7. To demonstrating the applications of group theory in various areas of mathematics, such as number theory, geometry, cryptography, and particle physics.

Course Outcomes:

CO1: Students will be able to understand the abstract algebra, particularly in relation to and be able to articulate the key concepts and properties associated with groups.
CO2: Students will be able to explain the significance of the notions of cosets, normal subgroups and factor groups.
CO3: Students will be able to analyse consequences of Lagrange's theorem.
CO4: Students will be able to recognize group structures in various mathematical contexts and understand how different mathematical objects can be analyzed using group theory.
CO5: Students will be able to describe about structure preserving maps between groups and their consequences.
CO6: Students will be able to construct clear and rigorous mathematical proofs related to group theory concepts and theorems, demonstrating logical reasoning and mathematical maturity.
CO7: Students will be able to apply group theory concepts and techniques to solve problems in mathematics and related fields, such as cryptography, particle physics, and chemistry.

Topics and Learning Points

	Teaching Hours
Unit 1: Introduction to Groups	**04**
1.1 Symmetries of square and the Dihedral groups	
1.2 Definition and examples of groups	
1.3 Elementary properties of groups	
Unit 2: Finite Groups and Subgroups	**06**
2.1 Order of group, Order of elements	
2.2 Subgroup Tests and examples	
2.3 Center of a group and Centralizer of element	
2.4 Cosets: definition and properties	
2.5 Lagrange's theorem and corollary	
Unit 3: Cyclic Groups	**05**
3.1 Properties of cyclic groups and examples	
3.2 Order of finite cyclic groups	
3.3 Generators of finite cyclic groups	
3.4 Fundamental theorem of Cyclic Groups	
Unit 4: Permutation Groups	**05**
4.1 Definition and examples	
4.2 Permutation on S_n, detail discussion of S_3	
4.3 Properties and theorems on permutation	
4.4 Even odd permutation	
Unit 5: Normal Subgroup	**04**
5.1 Definition	
5.2 Theorems on Normal subgroup	
Unit 6: Homomorphism and Isomorphism's	**06**
6.1 Homomorphism and fundamental theorem of homomorphism	
6.2 Group isomorphism's	
6.3 Cayley's Theorem	
6.4 Properties of isomorphism	
6.5 Automorphisms	

Text Book:

Joseph Gallian, *Contemporary Abstract Algebra*, Narosa Publishing House.
Unit 1: Chapter 1 & 2, **Unit 2:** Chapter 3, **Unit 3:** Chapter 4,
Unit 4: Chapter 5, **Unit 5:** Chapter 9, **Unit 6:** Chapter 6 & 10.

Reference Books:

1. P. B. Bhattacharya, S. K. Jain and S. R. Nagpal, *Basic Abstract Algebra*, Cambridge University Press.
2. I. S. Luthar and Inder Bir S. Passi, *Algebra: Groups*, Narosa Publishing House.
3. I.N. Herstein, *Topics in Algebra*, Wiley.
4. J. B. Fraleigh, A. *First Course in Abstract Algebra*, Narosa Publishing House.
5. M. Artin, *Algebra*, Prentice Hall of India, New Delhi.

CO-PO Mapping

Weightage: 1 – weak or low relation, 2 – moderate or partial relation, 3 – strong or direct relation

Programme Outcomes	Course Outcomes						
	CO1	CO2	CO3	CO4	CO5	CO6	CO7
PO01	3	3	3	3	3	3	3
PO02	2	2	2	3	3	3	3
PO03	1	1	1	2	2	2	3
PO04	2	2	2	3	3	3	3
PO05	2	2	3	3	3	3	3
PO06	1	1	1	2	2	3	2
PO07	1	2	2	2	3	3	3
PO08	2	2	2	2	3	3	3
PO09	1	1	1	2	2	2	3
PO10	1	1	1	2	2	2	2
PO11	1	1	1	1	1	1	2
PO12	1	1	1	2	2	3	3
PO13	1	1	1	1	2	2	3

Justification for the mapping

PO1: ***Comprehensive knowledge and understanding*** - CO1 to CO7 have a strong relation as understanding abstract algebra, groups, cosets, normal subgroups, and applications in various fields requires comprehensive knowledge.

PO2: ***Practical, professional, and procedural knowledge*** - CO4 to CO7 have a strong relation since recognizing group structures, structure-preserving maps, and mathematical proofs are essential for professional and procedural expertise and CO1 to CO3 have a moderate relation as they contribute to foundational knowledge that supports practical applications.

PO3: ***Entrepreneurial mindset and knowledge*** **-** CO7 has a strong relation since applications of group theory in fields like cryptography and physics align with innovation and entrepreneurship, CO4 to CO6 have a moderate relation as they contribute to analytical thinking needed for problem-solving in various domains and CO1 to CO3 have a weak relation as they primarily focus on theoretical foundations.

PO4: ***Specialized skills and competencies*** - CO4 to CO7 have a strong relation as they focus on recognizing group structures, proving theorems, and applying abstract algebra in problem-solving and CO1 to CO3 have a moderate relation as they provide foundational understanding necessary for specialization.

PO5: ***Capacity for Application, Problem-Solving, and Analytical Reasoning*** - CO3 to CO7 have a strong relation as analyzing Lagrange's theorem, proving theorems, and applying group theory require analytical and problem-solving skills and CO1 and CO2 have a moderate relation as understanding concepts is a prerequisite for applying them.

PO6: ***Communication skills and collaboration*** - CO6 has a strong relation since constructing rigorous mathematical proofs requires clear and structured communication, CO4, CO5, and CO7 have a moderate relation as they involve mathematical discussions and collaborative problem-solving and CO1 to CO3 have a weak relation as they mainly focus on individual understanding.

PO7: ***Research-related skills*** - CO5 to CO7 have a strong relation since proving theorems and applying group theory concepts are essential for mathematical research, CO2 to CO4 have a moderate relation as they provide foundational knowledge necessary for research and CO1 has a weak relation as it focuses on basic conceptual understanding.

PO8: ***Learning how to learn skills*** **-** CO5 to CO7 have a strong relation as proving theorems and applying concepts require continuous learning and adaptation and CO1 to CO4 have a moderate relation since understanding abstract algebra enhances logical reasoning and learning abilities.

PO9: ***Digital and technological skills*** **-** CO7 has a strong relation as applications in cryptography and physics often involve computational tools, CO4 to CO6 have a moderate relation as group theory concepts can be implemented using software tools and CO1 to CO3 have a weak relation since they are mainly theoretical.

PO10: ***Multicultural competence, inclusive spirit, and empathy*** - CO4 to CO7 have a moderate relation as group theory is used in diverse scientific and mathematical contexts, fostering an appreciation for global contributions to mathematics and CO1 to CO3 have a weak relation as they focus on theoretical concepts without direct multicultural aspects.

PO11: ***Value inculcation and environmental awareness*** - CO7 has a moderate relation as applications in cryptography and physics can contribute to technological advancements with societal impacts and CO1 to CO6 have a weak relation since they primarily focus on theoretical knowledge.

PO12: ***Autonomy, responsibility, and accountability*** **-** CO6 and CO7 have a strong relation as proving theorems and applying group theory require independent thought and responsibility, CO4 and CO5 have a moderate relation as they involve structured learning and self-discipline and CO1 to CO3 have a weak relation as they focus more on foundational understanding rather than independent work.

PO13: ***Community engagement and service*** - CO7 has a strong relation since applications in cryptography, physics, and chemistry can benefit society, CO5 and CO6 have a moderate relation as they encourage logical thinking and structured communication, which are valuable for community-based projects and CO1 to CO4 have a weak relation as they focus on theoretical aspects with limited direct societal engagement.

CBCS Syllabus as per NEP 2020 for T.Y.B.Sc. Mathematics (2023 Pattern)

Name of the Programme : B.Sc. Mathematics
Program Code : USMT
Class : T.Y.B.Sc.
Semester : V
Course Type : Major Mandatory
Course Name : Elementary Number Theory
Course Code : MAT-304-MJM
No. of Teaching Hours : 30
No. of Credits : 2

Course Objectives:

1. To develop a solid understanding of divisibility properties of integers, including the Division Algorithm and the Fundamental Theorem of Arithmetic.
2. To introduce the concept of congruences and explore their properties, including residue classes and theorems like Fermat's, Euler's, and Wilson's.
3. To investigate the greatest integer function and related arithmetic functions like Euler's function, divisor function, sum of divisors function, and number of prime divisors function.
4. To introduce the concept of multiplicative functions and explore the Mobius function and its inversion formula.
5. To develop an understanding of quadratic residues, Legendre's symbol, and the Law of Quadratic Reciprocity.
6. To introduce Jacobi symbol as an extension of Legendre's symbol.
7. To expose students to Diophantine equations, focusing on linear equations ($ax + by = c$) and explore Pythagorean triplets as an example.

Course Outcomes:

CO1: Students will be able to apply divisibility properties and the Division Algorithm to solve problems involving integers.
CO2: Students will be able to perform operations on congruence classes and utilize theorems like Fermat's, Euler's, and Wilson's to solve problems.
CO3: Students will be able to calculate the greatest integer function and related arithmetic functions for various integers.
CO4: Students will be able to identify and utilize multiplicative functions, particularly the Mobius function and its inversion formula.
CO5: Students will be able to determine quadratic residues and apply Legendre's symbol to solve problems related to quadratic reciprocity.
CO6: Students will be able to understand the concept of Jacobi symbol and its connection to Legendre's symbol.
CO7: Students will be able to solve linear Diophantine equations and identify Pythagorean triplets using number theory concepts.

Topics and Learning Points

	Teaching Hours
Unit 1: Divisibility	**07**
1.1 Divisibility in integers, Division Algorithm	
1.2 Greatest common divisor and least common multiple	
1.3 Fundamental theorem of Arithmetic	
1.4 Infinitude of primes	
Unit 2: Congruences	**08**
2.1 Properties of Congruences	
2.2 Residue classes, complete and reduced residue system, their properties	
2.3 Fermat's theorem. Euler's theorem, Wilson's theorem	
2.4 Linear Congruences of degree 1	
2.5 Chinese remainder theorem	
Unit 3: Greatest integer function	**06**
3.1 Arithmetic functions Euler's function	
3.2 the number of divisors $d(n)$	
3.3 $\sigma(n)$, $\omega(n)$ and $\Omega(n)$	
3.4 Multiplicative functions, Mobius function, Mobius inversion formula	
Unit 4: Quadratic Reciprocity	**05**
4.1 Quadratic residues	
4.2 Legendre's symbol and its properties	
4.3 Law of quadratic reciprocity	
4.4 Jacobi symbol	
Unit 5: Diophantine Equations	**04**
5.1 Diophantine Equations $ax + by = c$	
5.2 Pythagorean triplets	

Text Book:

I. Niven, H. Zuckerman and H.L. Montgomery, *An Introduction to Theory of Numbers*, John Wiley and Sons, 5^{th} Edition.

Unit 1: Sections 1.1 to 1.3, **Unit 2:** Sections 2.1 to 2.3, **Unit 3:** Sections 4.1 to 4.4, **Unit 4:** Sections 3.1 to 3.3, **Unit 5:** Sections 5.1 to 5.3.

Reference Books:

1. David M. Burton, *Elementary Number Theory*, McGraw-Hill, 1996.
2. Joseph H. Silverman, *A Friendly Introduction to Number Theory*, Pearson.
3. George E. Andrews, *Number Theory*, Dover Publications, 1994.
4. Titu Andreescu and Dorin Andrica, *Number Theory: Structures, Examples and Problems*, Springer.
5. Benjamin Fine and Gerhard Rosenberger, *Number Theory*, Birkhauser.

CO-PO Mapping

Weightage: 1 – weak or low relation, 2 – moderate or partial relation, 3 – strong or direct relation

Programme Outcomes	Course Outcomes						
	CO1	CO2	CO3	CO4	CO5	CO6	CO7
PO01	3	3	3	3	3	3	3
PO02	3	3	2	2	3	2	3
PO03	1	1	1	1	2	1	2
PO04	2	3	2	3	3	3	3
PO05	3	3	3	3	3	3	3
PO06	1	1	1	1	1	1	2
PO07	2	3	2	3	3	3	3
PO08	3	3	3	3	3	3	3
PO09	1	2	1	2	2	2	2
PO10	1	1	1	1	1	1	1
PO11	1	1	1	1	1	1	1
PO12	2	2	2	2	2	2	2
PO13	1	1	1	1	1	1	2

Justification for the mapping

PO1: ***Comprehensive knowledge and understanding*** - CO1 to CO7 are strongly related because understanding number theory concepts such as divisibility, congruences, arithmetic functions, and Diophantine equations requires a strong foundation in theoretical knowledge.

PO2: ***Practical, professional, and procedural knowledge*** - CO1, CO2, CO5, and CO7 are strongly related since they involve applying theoretical number theory concepts to solve practical mathematical problems and CO3, CO4, and CO6 have a moderate relation as they focus on theoretical aspects but also include computational techniques.

PO3: ***Entrepreneurial mindset and knowledge*** **-** CO5 and CO7 have a weak-to-moderate relation, as number theory finds applications in cryptography and digital security, which are relevant for entrepreneurship in technology and other COs have a weak relation because their focus is mainly on theoretical aspects rather than direct entrepreneurial applications.

PO4: ***Specialized skills and competencies*** - CO2, CO4, CO5, CO6, and CO7 are strongly related since they involve specialized number-theoretic skills like Euler’s theorem, Möbius inversion, Legendre's symbol, and Diophantine equations while CO1 and CO3 have a moderate relation as they involve fundamental number-theoretic properties.

PO5: ***Capacity for Application, Problem-Solving, and Analytical Reasoning*** - All COs are strongly related because number theory requires critical problem-solving skills and logical reasoning to analyze and solve mathematical problems.

PO6: ***Communication skills and collaboration*** - All COs have a weak relation because number theory is mostly theoretical and computational, with limited direct emphasis on communication and teamwork while CO7 has a slightly higher weightage as solving Diophantine equations can involve collaborative research efforts.

PO7: ***Research-related skills*** - CO2, CO4, CO5, CO6, and CO7 are strongly related since they involve advanced number theory topics relevant to research and CO1 and CO3 have a moderate relation as they form a foundational basis for further research in the field.

PO8: ***Learning how to learn skills*** - All COs are strongly related as number theory requires self-learning and problem-solving strategies to understand and explore advanced mathematical concepts.

PO9: ***Digital and technological skills*** - CO2, CO4, CO5, CO6, and CO7 have a moderate relation as number theory is widely used in cryptography, computer science, and digital security and CO1 and CO3 have a weaker relation as they focus more on classical number theory concepts.

PO10: ***Multicultural competence, inclusive spirit, and empathy*** - All COs have a weak relation since number theory does not directly contribute to multicultural competence or inclusivity. However, mathematical discoveries have been contributed by various cultures, and an appreciation of historical developments in number theory can support inclusivity.

PO11: ***Value inculcation and environmental awareness*** - All COs have a weak relation since number theory does not directly address ethical or environmental concerns. However, logical thinking and precision in problem-solving can contribute to responsible academic conduct.

PO12: ***Autonomy, responsibility, and accountability*** - All COs have a moderate relation as solving number theory problems requires self-directed learning, critical thinking, and independent problem-solving.

PO13: ***Community engagement and service*** - CO7 has a slightly higher relation as concepts like Diophantine equations and Pythagorean triplets have historical significance in various cultures, which can be linked to mathematical outreach and education.

CBCS Syllabus as per NEP 2020 for T.Y.B.Sc. Mathematics (2023 Pattern)

Name of the Programme	: B.Sc. Mathematics
Program Code	: USMT
Class	: T.Y.B.Sc.
Semester	: V
Course Type	: Major Mandatory
Course Name	: Practical on Analysis and Algebra – I
Course Code	: MAT-305-MJM
No. of Teaching Hours	: 60
No. of Credits	: 2

Course Objectives:

1. To develop an understanding of sequences, their convergence, and the concept of completeness in metric spaces.
2. To explore fundamental topological properties such as open and closed sets, continuity, connectedness, and compactness in metric spaces.
3. To analyze the properties of sets, functions, and real numbers with a focus on least upper bounds and completeness.
4. To investigate the convergence and boundedness of sequences, including limit superior and limit inferior.
5. To understand series convergence, absolute convergence, and the ℓ^2 class in mathematical analysis.
6. To introduce group theory concepts, including dihedral groups, cyclic groups, homomorphisms, and isomorphisms, with applications.
7. To study number theory concepts such as divisibility, the fundamental theorem of arithmetic, congruences, and arithmetic functions.

Course Outcomes:

CO1: Students will be able to determine the convergence of sequences and analyze completeness in metric spaces.
CO2: Students will apply topological concepts to metric spaces, including continuity, connectedness, and compactness.
CO3: Students will demonstrate an understanding of real number properties, functions, and the least upper bound principle.
CO4: Students will analyze and interpret sequence behavior using concepts such as boundedness, limit superior, and limit inferior.
CO5: Students will compute and assess the convergence of series, including absolute convergence and applications of the ℓ^2 class.
CO6: Students will apply fundamental group theory concepts, including dihedral groups, cyclic groups, and group homomorphisms, to algebraic structures.
CO7: Students will solve problems involving divisibility, congruences, Chinese Remainder Theorem, and arithmetic functions in number theory.

Topics and Learning Points

Teaching Hours

List of practical: **60**

1) Exploring Sequences and Completeness in Metric Spaces
2) Topology and Continuity in Metric Spaces
3) Connectedness and Compactness in Metric Spaces
4) Exploring Sets, Functions, and Real Numbers with Least Upper Bounds
5) Convergence and Boundedness of Sequences with Limit Superior and Inferior
6) Understanding Series: Convergence, Absolute Convergence, and ℓ^2 Class
7) Exploring Symmetries: Understanding the Dihedral Group and Basic Group Properties
8) Investigating Cyclic Groups: Generators, Orders, and Fundamental Theorem
9) Understanding Group Homomorphisms and Isomorphisms with Applications
10) Exploring Divisibility and the Fundamental Theorem of Arithmetic
11) Applications of Congruences and the Chinese Remainder Theorem
12) Arithmetic Functions and the Möbius Inversion Formula

CO-PO Mapping

Weightage: 1 – weak or low relation, 2 – moderate or partial relation, 3 – strong or direct relation

Programme Outcomes	Course Outcomes						
	CO1	CO2	CO3	CO4	CO5	CO6	CO7
PO01	3	3	3	3	3	3	3
PO02	3	3	3	3	3	3	3
PO03	2	2	1	1	1	1	2
PO04	3	3	3	3	3	3	3
PO05	3	3	3	3	3	3	3
PO06	2	2	1	1	1	1	2
PO07	3	3	3	3	3	3	3
PO08	3	3	3	3	3	3	3
PO09	1	1	1	1	1	1	2
PO10	1	1	1	1	1	1	1
PO11	1	1	1	1	1	1	1
PO12	2	2	2	2	2	2	3
PO13	1	1	1	1	1	1	2

Justification for the mapping

PO1: ***Comprehensive knowledge and understanding*** - CO1 to CO7 are strongly related because all course outcomes focus on building foundational knowledge in number theory, metric spaces, and algebraic structures.

PO2: ***Practical, professional, and procedural knowledge*** - CO1 to CO7 require students to apply number theory and metric space concepts to solve real mathematical problems, making this a strong relation.

PO3: ***Entrepreneurial mindset and knowledge*** **-** CO1 and CO2 moderately contribute, as number theory has applications in cryptography and security, CO3 to CO6 have a weaker relation since they focus more on theoretical aspects and CO7 has a moderate relation due to its application in computational number theory.

PO4: ***Specialized skills and competencies*** - CO1 to CO7 require deep analytical skills and specialized knowledge in number theory, making this a strong relation.

PO5: ***Capacity for Application, Problem-Solving, and Analytical Reasoning*** - CO1 to CO7 emphasize mathematical reasoning and problem-solving, making this a strong relation.

PO6: ***Communication skills and collaboration*** - CO1 and CO2 moderately contribute as they require explaining mathematical concepts clearly, CO3 to CO6 have a weaker relation since they focus more on computation and proofs and CO7 has a moderate relation due to its connection with collaborative problem-solving.

PO7: ***Research-related skills*** - CO1 to CO7 strongly contribute, as students engage in logical reasoning, proof construction, and theorem application.

PO8: ***Learning how to learn skills*** - CO1 to CO7 require students to independently explore and apply mathematical theorems, making this a strong relation.

PO9: ***Digital and technological skills*** - CO1 to CO6 have a weak relation since the focus is on theoretical mathematics and CO7 has a moderate relation as computational tools can be used to solve number theory problems.

PO10: ***Multicultural competence, inclusive spirit, and empathy*** - CO1 to CO7 have a weak relation since this course does not directly focus on these aspects.

PO11: ***Value inculcation and environmental awareness*** - CO1 to CO7 have a weak relation as the course does not directly address these values.

PO12: ***Autonomy, responsibility, and accountability*** **-** CO1 to CO6 have a moderate relation as students must independently solve mathematical problems and CO7 has a strong relation because solving complex Diophantine equations requires responsibility in mathematical reasoning.
PO13: ***Community engagement and service*** **-** CO1 to CO6 have a weak relation as the course is more theoretical and CO7 has a moderate relation because number theory concepts are applied in cybersecurity and coding theory, which have societal benefits.

CBCS Syllabus as per NEP 2020 for T.Y.B.Sc. Mathematics (2023 Pattern)

Name of the Programme	**:** B.Sc. Mathematics
Program Code	**:** USMT
Class	**:** T.Y.B.Sc.
Semester	**:** V
Course Type	**:** Major Elective
Course Name	**:** Partial Differential Equations
Course Code	**:** MAT-306-MJE (A)
No. of Teaching Hours	**:** 30
No. of Credits	**:** 2

Course Objectives:

1. To develop a solid understanding of surfaces and curves in three-dimensional space, which are foundational in solving differential equations in multiple variables.
2. To learn to solve simultaneous differential equations of the first order and first degree in three variables, a crucial skill for dealing with complex systems.
3. To gain proficiency in the theory and solution techniques for Pfaffian differential equations, a critical component in advanced mathematical modeling.
4. To develop the ability to derive and solve first-order partial differential equations, with an emphasis on understanding their origins and applications.
5. To learn to apply Cauchy’s method of characteristics for solving nonlinear first-order partial differential equations.
6. To investigate the concept of orthogonal trajectories and their application in various types of differential equations.
7. To develop skills in advanced solution methods such as Charpit’s method and other techniques for solving nonlinear partial differential equations.

Course Outcomes:

CO1: Students will be able to apply concepts of surfaces and curves in three dimensions to solve complex differential equations.
CO2: Students will demonstrate the ability to solve simultaneous differential equations involving multiple variables with accuracy.
CO3: Students will be able to identify, formulate, and solve Pfaffian differential equations in both two and three variables.
CO4: Students will develop the ability to analyze first-order partial differential equations and apply appropriate solution methods to real-world problems.
CO5: Students will demonstrate proficiency in applying Cauchy’s method of characteristics to solve nonlinear partial differential equations.
CO6: Students will be able to construct integral surfaces passing through a given curve and understand their significance in physical and engineering contexts.
CO7: Students will be equipped to solve nonlinear first-order partial differential equations using Charpit’s method and other advanced techniques.

Topics and Learning Points

Teaching Hours

Unit 1: Ordinary Differential Equations in more than two variables **07**

1.1 Surface and curves in three dimensions
1.2 Simultaneous Differential Equations of the first order and first degree in 3 variables
1.3 Methods of solution of $dx/P = dy/Q = dz/R$
1.4 Orthogonal trajectories of a system of curves on a surface

Unit 2: Pfaffian Differential Equations **06**

2.1 Pfaffian Differential forms and Differential Equations
2.2 Solution of Pfaffian Differential Equations in two variables
2.3 Solution of Pfaffian Differential Equations in three variables

Unit 3: Partial Differential Equations of the first order **08**

3.1 Partial Differential Equations
3.2 Origins of first-order Partial Differential Equations
3.3 Cauchy's problem for first -order equations
3.4 Linear equations of the first order
3.5 Integral surfaces passing through a given curve
3.6 Surfaces orthogonal to a given system of surfaces

Unit 4: Nonlinear Partial Differential Equations of the first order **09**

4.1 Definition of nonlinear Partial Differential Equations of the first order
4.2 Cauchy's method of characteristics
4.3 Compatible systems of first-order equations
4.4 Charpit's method
4.5 Special types of first-order equations

Text Book:

Ian Sneddon, *Element of Partial Differential Equations*, McGraw-Hill Book Company.

Unit 1: Ch. 1, Section 1 to 4, **Unit 2:** Ch. 1, Section 5 and 6,
Unit 3: Ch. 2, Section 1 to 6, **Unit 4:** Ch. 2, Section 7 to 11.

Reference Books:

1. W. E. Williams, *Partial Differential Equations*, Clarendon Press, Oxford.
2. K. Sankara Rao, *Introduction to Partial Differential Equations*, Third Edition, PHI.
3. T. Amaranath, *An Elementary Course in Partial Differential Equations*, Narosa Publishing, House 2nd Edition, 2003 (Reprint, 2006).
4. M. D. Raisinghania, *Ordinary and Partial Differential Equations*, S. Chand.
5. Stanley J. Farlow, *Partial Differential Equations for Scientists and Engineers*, Wiley.

CO-PO Mapping

Weightage: 1 – weak or low relation, 2 – moderate or partial relation, 3 – strong or direct relation

Programme Outcomes	Course Outcomes						
	CO1	CO2	CO3	CO4	CO5	CO6	CO7
PO01	3	3	3	3	3	3	3
PO02	3	3	3	3	3	3	3
PO03	2	2	2	2	2	2	2
PO04	3	3	3	3	3	3	3
PO05	3	3	3	3	3	3	3
PO06	2	2	2	2	2	2	2
PO07	3	3	3	3	3	3	3
PO08	3	3	3	3	3	3	3
PO09	2	2	2	2	2	2	2
PO10	1	1	1	1	1	1	1
PO11	1	1	1	1	1	1	1
PO12	2	2	2	2	2	2	2
PO13	1	1	1	1	1	1	1

Justification for the mapping

PO1: ***Comprehensive knowledge and understanding*** - CO1 to CO7 involve in-depth understanding of surfaces, curves, differential equations, and their applications in three-dimensional space. This aligns with the requirement of comprehensive mathematical knowledge.

PO2: ***Practical, professional, and procedural knowledge*** - The ability to solve simultaneous differential equations, partial differential equations, and apply advanced methods like Charpit's method demonstrates practical and procedural expertise.

PO3: ***Entrepreneurial mindset and knowledge*** **-** Some aspects of differential equations have applications in engineering, physics, and financial modeling, which can contribute to entrepreneurial ventures, but this is not a primary focus.

PO4: ***Specialized skills and competencies*** - The course focuses on specialized mathematical techniques like Cauchy's method, Charpit's method, and integral surfaces, which require advanced analytical skills.

PO5: ***Capacity for Application, Problem-Solving, and Analytical Reasoning*** - The ability to analyze and solve various types of differential equations directly contributes to problem-solving and analytical thinking.

PO6: ***Communication skills and collaboration*** - While the course primarily focuses on mathematical problem-solving, students are expected to communicate solutions effectively, especially in research or interdisciplinary collaborations.

PO7: ***Research-related skills*** - The advanced mathematical techniques covered in this course are essential for research in applied mathematics, physics, and engineering.

PO8: ***Learning how to learn skills*** - The nature of the course requires continuous learning, exploring new methods, and adapting to problem-solving strategies, which fosters independent learning.

PO9: ***Digital and technological skills*** - While the course does not focus directly on digital skills, solving differential equations often involves computational tools and software like MATLAB or Mathematica.

PO10: ***Multicultural competence, inclusive spirit, and empathy*** **-** The course primarily deals with mathematical concepts, with limited direct impact on multicultural competence and inclusivity.
PO11: ***Value inculcation and environmental awareness*** - Although mathematical models can be used for environmental studies, this course does not explicitly focus on environmental awareness.
PO12: ***Autonomy, responsibility, and accountability*** - Solving complex mathematical problems requires discipline, responsibility, and independent work, contributing to personal and academic accountability.
PO13: ***Community engagement and service*** - The course does not have a direct focus on community engagement, though mathematical modeling can have societal applications.

CBCS Syllabus as per NEP 2020 for T.Y.B.Sc. Mathematics (2023 Pattern)

Name of the Programme	**:** B.Sc. Mathematics
Program Code	**:** USMT
Class	**:** T.Y.B.Sc.
Semester	**:** V
Course Type	**:** Major Elective
Course Name	**:** Fundamentals of Graph Theory
Course Code	**:** MAT-306-MJE (B)
No. of Teaching Hours	**:** 30
No. of Credits	**:** 2

Course Objectives:

1. To introduce the fundamental concepts of graph theory and explore its real-world applications.
2. To define and analyze different types of graphs through examples and puzzles.
3. To study paths and cycles, including connectivity, Eulerian graphs, and Hamiltonian graphs.
4. To understand tree structures, their properties, and methods for counting and applying trees.
5. To investigate directed graphs (digraphs) and their significance in various applications.
6. To explore algorithms related to graph theory for solving practical problems.
7. To examine advanced topics such as Eulerian digraphs, tournaments, and Markov chains.

Course Outcomes:

CO1: Students will be able to define and identify different types of graphs and their real-world significance.

CO2: Students will demonstrate an understanding of connectivity, Eulerian graphs, and Hamiltonian graphs.

CO3: Students will be able to apply algorithms to analyze paths and cycles in graphs.

CO4: Students will understand the properties of trees and effectively count and apply them in various contexts.

CO5: Students will analyze the structure of directed graphs and their applications.

CO6: Students will be able to apply concepts of Eulerian digraphs and tournaments to solve problems.

CO7: Students will demonstrate an understanding of Markov chains and their applications in graph theory.

Topics and Learning Points

	Teaching Hours
Unit 1: Introduction	**08**
1.1 What is a graph?	
1.2 Definition and examples	
1.3 Three puzzles	
Unit 2: Paths and cycles	**07**
2.1 Connectivity	
2.2 Eulerian graphs	
2.3 Hamiltonian graphs	
2.4 Some algorithms	
Unit 3: Trees	**08**
3.1 Properties of trees	
3.2 Counting trees	
3.3 More applications	
Unit 4: Digraphs	**07**
4.1 Definitions	
4.2 Eulerian digraphs and tournaments	
4.3 Markov chains	

Text Book:

Robin J. Wilson, *Introduction to Graph Theory*, Printice Hall, 4th Edition.
Unit 1: Sections 1 to 4, **Unit 2:** Sections 5 to 8,
Unit 3: Sections 9 to 11, **Unit 4:** Sections 22 to 24.

Reference Books:

1. John Clark and Derek Allan Holton, *A first look at Graph Theory*, Allied Publishers Ltd., 1995.
2. Narsingh Deo, *Graph Theory with Applications to Engineering & Computer Science*, Dover Publications.
3. R. Balakrishnan and K. Ranganathan, *A Textbook of Graph Theory*, Springer.
4. Geir Agnarsson and Raymond Greenlaw, *Graph Theory: Modeling, Applications and Algorithms*, Pearson.
5. Frank Harary, *Graph Theory*, Additon-Wesley, 1971.

CO-PO Mapping

Weightage: 1 – weak or low relation, 2 – moderate or partial relation, 3 – strong or direct relation

Programme Outcomes	Course Outcomes						
	CO1	CO2	CO3	CO4	CO5	CO6	CO7
PO01	3	3	3	3	3	3	3
PO02	2	3	3	2	3	3	3
PO03	1	1	2	1	2	2	2
PO04	2	2	3	3	3	3	3
PO05	2	3	3	3	3	3	3
PO06	1	1	2	1	1	2	2
PO07	1	2	3	2	3	3	3
PO08	2	3	3	3	3	3	3
PO09	1	1	2	1	2	2	3
PO10	1	1	1	1	1	1	1
PO11	1	1	1	1	1	1	1
PO12	2	2	2	2	2	3	3
PO13	1	1	1	1	1	1	1

Justification for the mapping

PO1: ***Comprehensive knowledge and understanding*** - CO1 to CO7 are rated 3 because the course provides a fundamental and in-depth understanding of graph theory, covering key concepts like graph types, connectivity, paths, cycles, trees, directed graphs, Eulerian digraphs, tournaments, and Markov chains.

PO2: ***Practical, professional, and procedural knowledge*** - CO2 to CO7 are rated 3 as they involve practical problem-solving approaches such as analyzing paths, cycles, trees, and Markov chains while CO1 and CO4 are rated 2 since they contribute to theoretical knowledge but are not heavily application-driven.

PO3: ***Entrepreneurial mindset and knowledge*** **-** CO3, CO5, CO6, and CO7 are rated 2 because applying graph theory to problem-solving can lead to innovative solutions in network analysis, logistics, and decision-making and CO1, CO2, and CO4 are rated 1 as they provide foundational knowledge but have limited direct entrepreneurial applications.

PO4: ***Specialized skills and competencies*** - CO3 to CO7 are rated 3 as they develop specialized skills in graph algorithms, Markov chains, Eulerian digraphs, and tournament applications while CO1 and CO2 are rated 2 since they focus on basic graph classifications and properties.

PO5: ***Capacity for Application, Problem-Solving, and Analytical Reasoning*** - CO2 to CO7 are rated 3 as they involve applying algorithms, problem-solving in graphs, and analytical reasoning to solve real-world graph problems and CO1 is rated 2 since identifying and defining graphs is foundational but does not directly involve problem-solving.

PO6: ***Communication skills and collaboration*** - CO3 and CO6 are rated 2 as discussing graph theory problems and solutions in teams requires communication and collaborative skills and CO1, CO2, CO4, CO5, and CO7 are rated 1 since they primarily focus on mathematical concepts rather than communication.

PO7: ***Research-related skills*** - CO3 to CO7 are rated 3 as they involve deep problem-solving techniques used in research areas like network theory, stochastic processes, and optimization, CO2 is rated 2 as connectivity and graph traversal play a role in research but not at an advanced level and CO1 is rated 1 since defining and classifying graphs is essential but not research-intensive.

PO8: ***Learning how to learn skills*** - CO2 to CO7 are rated 3 because they require continuous learning and adaptation to new graph-related problems, especially in fields like data science and operations research and CO1 is rated 2 as it introduces basic concepts but does not heavily emphasize independent learning.

PO9: ***Digital and technological skills*** - CO3, CO5, CO6, and CO7 are rated 2 or 3 since graph algorithms are widely used in computer science, artificial intelligence, and network analysis and CO1, CO2, and CO4 are rated 1 as they focus more on theoretical understanding than digital applications.

PO10: ***Multicultural competence, inclusive spirit, and empathy*** - All COs are rated 1 since graph theory does not directly contribute to multicultural competence or empathy.

PO11: ***Value inculcation and environmental awareness*** - All COs are rated 1 since the course has no direct environmental or ethical component.

PO12: ***Autonomy, responsibility, and accountability*** - CO6 and CO7 are rated 3 as they require independent problem-solving and decision-making and CO1 to CO5 are rated 2 as they contribute to analytical thinking but do not strongly emphasize autonomy.

PO13: ***Community engagement and service*** - All COs are rated 1 since the course does not directly involve community engagement.

CBCS Syllabus as per NEP 2020 for T.Y.B.Sc. Mathematics (2023 Pattern)

Name of the Programme	**:** B.Sc. Mathematics
Program Code	**:** USMT
Class	**:** T.Y.B.Sc.
Semester	**:** V
Course Type	**:** Major Elective
Course Name	**:** Introduction to Numerical Analysis
Course Code	**:** MAT-306-MJE (C)
No. of Teaching Hours	**:** 30
No. of Credits	**:** 2

Course Objectives:

1. To introduce the need and importance of numerical methods in solving mathematical problems.
2. To develop an understanding of different types of numerical errors and their propagation in computations.
3. To familiarize students with numerical techniques for solving algebraic and transcendental equations.
4. To introduce interpolation methods for estimating unknown values from given data.
5. To equip students with numerical differentiation and integration techniques for approximating derivatives and integrals.
6. To apply numerical methods for solving ordinary and partial differential equations.
7. To enhance computational skills using numerical algorithms and improve problem-solving abilities.

Course Outcomes:

CO1: Students will be able to understand the significance of numerical methods and their applications in real-world problems.
CO2: Students will be able to analyze different types of errors and determine their effects on numerical computations.
CO3: Students will be able to apply numerical techniques such as Bisection, Regula-Falsi, and Newton-Raphson methods to solve equations.
CO4: Students will be able to use interpolation techniques like Newton's and Lagrange's formulas to estimate missing data points.
CO5: Students will be able to implement numerical differentiation and integration techniques for approximating derivatives and definite integrals.
CO6: Students will be able to solve ordinary and partial differential equations using methods such as Euler's and Runge-Kutta methods.
CO7: Students will be able to develop computational algorithms for numerical methods and apply them to practical scientific problems.

Topics and Learning Points

Teaching Hours

Unit 1: Basics of Numerical Methods & Errors **07**

1.1 Introduction to Numerical Methods: Need and importance
1.2 Types of Errors: Absolute, Relative, Percentage errors
1.3 Propagation of Errors in numerical computations
1.4 Floating-point Representation and its limitations
1.5 Numerical Solution of Algebraic and Transcendental Equations: Bisection Method, Regula-Falsi Method and Newton-Raphson Method

Unit 2: Interpolation & Curve Fitting **07**

2.1 Introduction to Interpolation: Need and applications
2.2 Finite Differences: Forward, Backward, and Central differences
2.3 Newton's Forward and Backward Interpolation Formulae
2.4 Lagrange's Interpolation Formula
2.5 Least Squares Approximation: Curve fitting using straight lines and polynomials

Unit 3: Numerical Differentiation and Integration **08**

3.1 Numerical Differentiation: Using finite difference methods
3.2 Numerical Integration: Trapezoidal Rule, Simpson's 1/3 Rule and Simpson's 3/8 Rule
3.3 Application of Numerical Integration: Approximating definite integrals

Unit 4: Numerical Solutions of Differential Equations **08**

4.1 Euler's Method: Solving first-order ODEs
4.2 Modified Euler's Method
4.3 Runge-Kutta Method
4.4 Finite Difference Methods for PDEs: Heat and Wave equations – Basic concepts

Text Book:

S. S. Sastry, *Introductory Methods of Numerical Analysis*, PHI Learning Pvt. Ltd., 5^{th} Edition.

Unit 1: Chapters 1 and 2, **Unit 2:** Chapters 3 and 4,
Unit 3: Chapter 6, **Unit 4:** Chapter 8 and 9.

Reference Books:

1. R. W. Hamming, *Numerical Methods for Scientists and Engineers*, McGraw-Hill.
2. Ralph G. Stanton, *Numerical Methods in Science and Engineering*, Printice-Hall.
3. Francis Scheid, *Numerical Analysis*, Schaum's Outline.
4. Rajasekaran S., *Numerical Methods in Science and Engineering: A Practical Approach*, S. Chand.
5. Brian Bradie, *A Friendly Introduction to Numerical Analysis*, Pearson Education India.

CO-PO Mapping

Weightage: 1 – weak or low relation, 2 – moderate or partial relation, 3 – strong or direct relation

Programme Outcomes	Course Outcomes						
	CO1	CO2	CO3	CO4	CO5	CO6	CO7
PO01	3	3	3	3	3	3	3
PO02	2	3	3	3	3	3	3
PO03	1	1	2	2	2	2	3
PO04	2	3	3	3	3	3	3
PO05	3	3	3	3	3	3	3
PO06	1	1	2	2	2	2	2
PO07	2	2	2	2	2	3	3
PO08	2	2	3	3	3	3	3
PO09	2	2	3	3	3	3	3
PO10	1	1	1	1	1	1	1
PO11	1	1	1	1	1	1	1
PO12	2	2	3	3	3	3	3
PO13	1	1	1	1	1	1	1

Justification for the mapping

PO1: ***Comprehensive knowledge and understanding*** - Numerical methods are fundamental to scientific computing and applied mathematics. Every CO contributes to building a strong conceptual understanding of these methods and their applications.

PO2: ***Practical, professional, and procedural knowledge*** - Understanding numerical errors, interpolation, differentiation, integration, and differential equation solvers equips students with practical skills necessary for solving real-world problems.

PO3: ***Entrepreneurial mindset and knowledge*** **-** Numerical algorithms are widely used in industry applications, including finance, engineering, and technology. Developing computational solutions fosters an entrepreneurial mindset by enabling students to create innovative solutions.

PO4: ***Specialized skills and competencies*** - The course equips students with specialized skills such as solving equations numerically, estimating missing data, approximating derivatives and integrals, and solving differential equations using numerical methods.

PO5: ***Capacity for Application, Problem-Solving, and Analytical Reasoning*** - Since numerical methods provide solutions to problems that do not have closed-form solutions, this course enhances students' analytical abilities and problem-solving skills across various domains.

PO6: ***Communication skills and collaboration*** - Although numerical methods primarily focus on computation, students must interpret results, present numerical findings, and collaborate on computational projects.

PO7: ***Research-related skills*** - Numerical methods play a crucial role in scientific research, including physics, engineering, and data science. Understanding error analysis and computational techniques prepares students for research applications.

PO8: ***Learning how to learn skills*** - The course introduces students to various iterative methods and computational techniques, encouraging continuous learning and adaptation to new numerical approaches.

PO9: ***Digital and technological skills*** - Implementing numerical methods requires programming and computational tools such as MATLAB, Python, or C, which enhance students' digital and technological competencies.

PO10: ***Multicultural competence, inclusive spirit, and empathy*** - While not directly related to numerical methods, working on collaborative projects fosters inclusivity and teamwork.
PO11: ***Value inculcation and environmental awareness*** - The impact of numerical simulations in environmental science and engineering can promote awareness of sustainability and ethical responsibility in computational research.
PO12: ***Autonomy, responsibility, and accountability*** - Numerical computing requires precision, validation, and verification of results, fostering a responsible and independent approach to problem-solving.
PO13: ***Community engagement and service*** - Numerical methods can be applied to social and community challenges, such as climate modeling, epidemiological studies, and economic forecasting, but the direct impact may be limited.

CBCS Syllabus as per NEP 2020 for T.Y.B.Sc. Mathematics (2023 Pattern)

Name of the Programme : B.Sc. Mathematics
Program Code : USMT
Class : T.Y.B.Sc.
Semester : V
Course Type : Minor
Course Name : Basic Abstract Algebra
Course Code : MAT-311-MN
No. of Teaching Hours : 30
No. of Credits : 2

Course Objectives:

1. To understand the fundamental concepts of semigroups and groups, including their structure and properties.
2. To explore group homomorphisms and isomorphisms, analyzing their role in abstract algebra.
3. To study subgroups, cosets, cyclic groups, and normal subgroups, emphasizing their significance in group theory.
4. To examine isomorphism theorems and their applications in understanding group structures.
5. To analyze permutation groups, cyclic decomposition, and alternating groups, exploring their algebraic properties.
6. To investigate the definitions, properties, and types of rings, including subrings and their characteristics.
7. To understand the concepts of ideals and ring homomorphisms and their role in algebraic structures.

Course Outcomes:

CO1: Students will be able to define and identify semigroups, groups, and related algebraic structures.
CO2: Students will demonstrate an understanding of group homomorphisms and isomorphisms, applying them to problem-solving.
CO3: Students will analyze subgroups, cosets, cyclic groups, and normal subgroups to determine their algebraic properties.
CO4: Students will apply isomorphism theorems to prove structural results in group theory.
CO5: Students will classify permutation groups, perform cyclic decomposition, and analyze alternating groups.
CO6: Students will describe different types of rings and subrings and compute their fundamental properties.
CO7: Students will apply the concepts of ideals and ring homomorphisms to solve problems in abstract algebra.

Topics and Learning Points

Topic	Teaching Hours
Unit 1: Groups	**10**
1.1 Semigroups and groups	
1.2 Homomorphisms	
1.3 Subgroups and cosets	
1.4 Cyclic groups	
1.5 Normal subgroups	
1.6 Isomorphism theorems	
Unit 2: Permutation groups	**06**
2.1 Permutation groups	
2.2 Cyclic decomposition	
2.3 Alternating group	
Unit 3: Rings	**08**
3.1 Definition and examples	
3.2 Elementary properties of rings	
3.3 Types of rings	
3.4 Subrings and characteristic of a ring	
Unit 4: Ideals and Homomorphisms	**06**
4.1 Ideals	
4.2 Homomorphisms	

Text Book:

P. B. Bhattacharya, S. K. Jain and S. R. Nagpal, *Basic Abstract Algebra*, Cambridge University Press, 2nd Edition.

Unit 1: Sections 4.1 to 4.4 & 5.1, **Unit 2:** Sections 7.1 & 7.2,
Unit 3: Sections 9.1 to 9.4, **Unit 4:** Sections 10.1 & 10.2.

Reference Books:

1. Joseph Gallian, *Contemporary Abstract Algebra*, Narosa Publishing House.
2. J. B. Fraleigh, A. *First Course in Abstract Algebra*, Narosa Publishing House.
3. M. Artin, *Algebra*, Prentice Hall of India, New Delhi.
4. I.N. Herstein, *Topics in Algebra*, Wiley.
5. David S. Dummit and Richard M. Foote, *Abstract Algebra*, Wiley.

CO-PO Mapping

Weightage: 1 – weak or low relation, 2 – moderate or partial relation, 3 – strong or direct relation

Programme Outcomes	Course Outcomes						
	CO1	CO2	CO3	CO4	CO5	CO6	CO7
PO01	3	3	3	3	3	3	3
PO02	2	3	3	3	3	2	3
PO03	1	1	2	2	2	1	2
PO04	2	3	3	3	3	2	3
PO05	3	3	3	3	3	3	3
PO06	1	2	2	2	2	1	2
PO07	2	3	3	3	3	2	3
PO08	2	3	3	3	3	2	3
PO09	1	2	2	2	2	1	2
PO10	1	1	1	1	1	1	1
PO11	1	1	1	1	1	1	1
PO12	2	3	3	3	3	2	3
PO13	1	2	2	2	2	1	2

Justification for the mapping

PO1: ***Comprehensive knowledge and understanding*** - Strongly related to all COs because students develop a deep understanding of semigroups, groups, rings, and related algebraic structures.

PO2: ***Practical, professional, and procedural knowledge*** - Strong relation to CO2, CO3, CO4, CO5, and CO7 since group homomorphisms, isomorphisms, and ring properties have practical applications in mathematical problem-solving. Moderate relation to CO1 and CO6 as they provide foundational knowledge.

PO3: ***Entrepreneurial mindset and knowledge*** **-** Weak to moderate relation, as abstract algebra concepts can contribute to problem-solving in cryptography, coding theory, and other applied areas, but direct entrepreneurial applications are limited.

PO4: ***Specialized skills and competencies*** - Strongly related to CO2, CO3, CO4, CO5, and CO7 since these involve high-level mathematical skills such as proving theorems and classifying algebraic structures. Moderate relation to CO1 and CO6.

PO5: ***Capacity for Application, Problem-Solving, and Analytical Reasoning*** - Strongly related to all COs as algebraic structures and proofs require analytical reasoning and problem-solving techniques.

PO6: ***Communication skills and collaboration*** - Moderately related to CO2, CO3, CO4, CO5, and CO7, as discussing proofs and collaborating in mathematical discussions are necessary. Weak relation to CO1 and CO6.

PO7: ***Research-related skills*** - Strongly related to CO2, CO3, CO4, CO5, and CO7, as abstract algebra provides a foundation for research in pure and applied mathematics. Moderate relation to CO1 and CO6.

PO8: ***Learning how to learn skills*** - Strongly related to CO2, CO3, CO4, CO5, and CO7, as abstract algebra involves learning new mathematical structures and techniques. Moderate relation to CO1 and CO6.

PO9: ***Digital and technological skills*** - Moderately related to CO2, CO3, CO4, CO5, and CO7, as algebraic structures are used in computational algebra systems and cryptographic algorithms. Weak relation to CO1 and CO6.

PO10: ***Multicultural competence, inclusive spirit, and empathy*** **-** Weak relation to all COs, as algebraic concepts are universal, but cultural aspects of mathematical collaboration might be relevant.
PO11: ***Value inculcation and environmental awareness*** - Weak relation, as abstract algebra does not directly address these aspects.
PO12: ***Autonomy, responsibility, and accountability*** - Strong relation to CO2, CO3, CO4, CO5, and CO7 since solving algebraic problems requires independent thinking and responsibility in mathematical rigor. Moderate relation to CO1 and CO6.
PO13: ***Community engagement and service*** - Moderately related to CO2, CO3, CO4, CO5, and CO7 since abstract algebra is used in fields like cryptography and coding theory, which impact society. Weak relation to CO1 and CO6.

CBCS Syllabus as per NEP 2020 for T.Y.B.Sc. Mathematics (2023 Pattern)

Name of the Programme	**:** B.Sc. Mathematics
Program Code	**:** USMT
Class	**:** T.Y.B.Sc.
Semester	**:** V
Course Type	**:** Minor
Course Name	**:** Practical based on Numerical Methods
Course Code	**:** MAT-312-MN
No. of Teaching Hours	**:** 60
No. of Credits	**:** 2

Course Objectives:

1. To introduce the need and importance of numerical methods in solving mathematical problems.
2. To develop an understanding of different types of numerical errors and their propagation in computations.
3. To familiarize students with numerical techniques for solving algebraic and transcendental equations.
4. To introduce interpolation methods for estimating unknown values from given data.
5. To equip students with numerical differentiation and integration techniques for approximating derivatives and integrals.
6. To apply numerical methods for solving ordinary and partial differential equations.
7. To enhance computational skills using numerical algorithms and improve problem-solving abilities.

Course Outcomes:

CO1: Students will be able to understand the significance of numerical methods and their applications in real-world problems.
CO2: Students will be able to analyze different types of errors and determine their effects on numerical computations.
CO3: Students will be able to apply numerical techniques such as Bisection, Regula-Falsi, and Newton-Raphson methods to solve equations.
CO4: Students will be able to use interpolation techniques like Newton's and Lagrange's formulas to estimate missing data points.
CO5: Students will be able to implement numerical differentiation and integration techniques for approximating derivatives and definite integrals.
CO6: Students will be able to solve ordinary and partial differential equations using methods such as Euler's and Runge-Kutta methods.
CO7: Students will be able to develop computational algorithms for numerical methods and apply them to practical scientific problems.

Topics and Learning Points

Teaching Hours

Theory: **12**

1. **Basics of Numerical Methods & Errors:** Absolute, Relative, Percentage errors, Bisection Method, Regula-Falsi Method and Newton-Raphson Method
2. **Interpolation & Curve Fitting:** Newton's Forward and Backward Interpolation Formulae, Lagrange's Interpolation Formula and Least Squares Approximation
3. **Numerical Differentiation and Integration:** Numerical Differentiation, Trapezoidal Rule, Simpson's 1/3 Rule and Simpson's 3/8 Rule
4. **Numerical Solutions of Differential Equations:** Euler's Method, Modified Euler's Method, Runge-Kutta Method and Finite Difference Methods for PDEs

List of practical: **48**

1. Error Analysis: Compute absolute, relative, and percentage errors in given numerical computations.
2. Solving Algebraic and Transcendental Equations using the Bisection Method.
3. Implementation of the Regula-Falsi Method for finding roots of equations.
4. Solving nonlinear equations using the Newton-Raphson Method and analyzing convergence.
5. Newton's Forward and Backward Interpolation: Estimating unknown values from given data.
6. Lagrange's Interpolation: Using Lagrange's formula for interpolation of tabulated data.
7. Curve Fitting: Fitting a straight line and quadratic curve using the least squares method.
8. Numerical Differentiation: Using finite differences to approximate derivatives.
9. Numerical Integration using Trapezoidal Rule and comparing with analytical results.
10. Numerical Integration using Simpson's 1/3 and 3/8 Rules.
11. Solving First-Order Differential Equations using Euler's Method.
12. Implementation of Runge-Kutta Method (RK4) to solve first-order ODEs.

Text Book:

S. S. Sastry, *Introductory Methods of Numerical Analysis*, PHI Learning Pvt. Ltd., 5th Edition.

Reference Books:

1. R. W. Hamming, *Numerical Methods for Scientists and Engineers*, McGraw-Hill.
2. Ralph G. Stanton, *Numerical Methods in Science and Engineering*, Printice-Hall.
3. Francis Scheid, *Numerical Analysis*, Schaum's Outline.
4. Rajasekaran S., *Numerical Methods in Science and Engineering: A Practical Approach*, S. Chand.
5. Brian Bradie, *A Friendly Introduction to Numerical Analysis*, Pearson Education India.

CO-PO Mapping

Weightage: 1 – weak or low relation, 2 – moderate or partial relation, 3 – strong or direct relation

Programme Outcomes	Course Outcomes						
	CO1	CO2	CO3	CO4	CO5	CO6	CO7
PO01	3	3	3	3	3	3	3
PO02	2	3	3	3	3	3	3
PO03	1	1	2	2	2	2	3
PO04	2	2	3	3	3	3	3
PO05	2	3	3	3	3	3	3
PO06	1	1	2	2	2	2	2
PO07	2	2	3	3	3	3	3
PO08	2	3	3	3	3	3	3
PO09	1	2	3	3	3	3	3
PO10	1	1	1	1	1	1	1
PO11	1	1	1	1	1	1	1
PO12	2	2	3	3	3	3	3
PO13	1	1	1	1	1	1	1

Justification for the mapping

PO1: ***Comprehensive knowledge and understanding*** - Numerical methods form a fundamental part of applied mathematics, providing students with a strong theoretical foundation for problem-solving across different scientific fields.

PO2: ***Practical, professional, and procedural knowledge*** - The application of numerical techniques to solve real-world mathematical problems enhances students' practical knowledge and professional problem-solving skills.

PO3: ***Entrepreneurial mindset and knowledge*** **-** Numerical techniques help in computational problem-solving, which is useful for startups and industries that rely on data analysis, simulations, and optimizations.

PO4: ***Specialized skills and competencies*** - Learning and implementing numerical methods equip students with specialized skills in approximation, error analysis, and algorithm development, which are critical for scientific computing.

PO5: ***Capacity for Application, Problem-Solving, and Analytical Reasoning*** - Numerical methods enable students to approach mathematical problems systematically, apply algorithms efficiently, and develop reasoning skills necessary for technical problem-solving.

PO6: ***Communication skills and collaboration*** - While numerical methods primarily focus on problem-solving, teamwork is often required when implementing these methods in computational projects and research.

PO7: ***Research-related skills*** - Many advanced research fields require numerical simulations, making numerical methods crucial for research in physics, engineering, economics, and data science.

PO8: ***Learning how to learn skills*** - The iterative and evolving nature of numerical methods requires students to continuously learn and adapt to new techniques and algorithms.

PO9: ***Digital and technological skills*** - Numerical methods involve computational techniques and software implementations, strengthening students' technological and programming skills.

PO10: ***Multicultural competence, inclusive spirit, and empathy*** - Although not directly related, numerical methods can be applied to interdisciplinary fields that require collaboration with diverse teams.

PO11: ***Value inculcation and environmental awareness*** - Numerical methods are used in environmental modeling, climate change analysis, and resource optimization, contributing to environmental awareness.

PO12: ***Autonomy, responsibility, and accountability*** - Working on numerical computations requires precision and accountability, as errors in calculations can have significant consequences in scientific and engineering applications.

PO13: ***Community engagement and service*** - Numerical methods contribute to community-based projects, such as disaster prediction models, infrastructure planning, and statistical analyses for social sciences.

CBCS Syllabus as per NEP 2020 for T.Y.B.Sc. Mathematics (2023 Pattern)

Name of the Programme	: B.Sc. Mathematics
Program Code	: USMT
Class	: T.Y.B.Sc.
Semester	: V
Course Type	: Vocational Skill Course
Course Name	: Practical Applications of LaTeX in Mathematical Documentation
Course Code	: MAT-321-VSC
No. of Teaching Hours	: 60
No. of Credits	: 2

Course Objectives:

1. To introduce students to the fundamentals of LaTeX, including text formatting, fonts, styles, and paragraphs.
2. To develop proficiency in typesetting mathematical expressions and equations with LaTeX.
3. To enable students to create structured documents using lists, tables, arrays, and sections.
4. To familiarize students with inserting figures and diagrams using TikZ and PGF for mathematical illustrations.
5. To teach students how to manage citations, references, and bibliographies effectively using BibTeX.
6. To equip students with the skills to compile and organize large documents such as articles, reports, and books.
7. To introduce students to Beamer for creating professional presentations and troubleshoot common LaTeX errors.

Course Outcomes:

CO1: Students will be able to format text, apply different font styles, and structure paragraphs in LaTeX.
CO2: Students will demonstrate the ability to typeset mathematical equations, symbols, and expressions correctly.
CO3: Students will create well-organized documents using lists, tables, arrays, and sectioning commands.
CO4: Students will insert and manipulate figures, diagrams, and illustrations using TikZ and PGF.
CO5: Students will effectively reference sources and manage bibliographies using LaTeX and BibTeX.
CO6: Students will compile and structure large-scale documents, ensuring clarity and coherence in academic writing.
CO7: Students will design professional mathematical presentations using Beamer and troubleshoot common LaTeX issues.

Topics and Learning Points

Teaching Hours

Theory: **12**

1. **Introduction to LaTeX and Basic Document Structure:** Overview of LaTeX, Installing and Setting Up LaTeX, Basic Document Structure, Writing and Formatting Text
2. **Mathematical Typesetting in LaTeX:** Inline and Display Math Modes, Common Mathematical Symbols and Operators, Formatting Equations, Matrices, Aligning Equations, and Multi-line Equations
3. **Structuring Documents and Advanced Features:** Creating Lists, Inserting Tables and Figures, Sections, Subsections, and Automatic Table of Contents, Referencing Equations, Theorems, and Bibliography with BibTeX
4. **Theorem Environments, Beamer Presentations, and Best Practices:** Writing Theorems, Definitions, Lemmas, and Proofs, Creating Beamer Presentations for Mathematical Talks, Compiling Large Documents and Handling Errors, Best Practices and Troubleshooting in LaTeX

List of practical: **48**

1. Formatting Text: Fonts, Styles, and Paragraphs
2. Typesetting Mathematical Expressions and Equations
3. Creating Lists, Tables, and Arrays in LaTeX
4. Inserting Figures and Diagrams using TikZ and PGF
5. Using Sections, Subsections, and Table of Contents
6. Referencing and Citing Sources in LaTeX
7. Writing and Formatting Theorems, Definitions, and Proofs
8. Creating and Managing Bibliographies with BibTeX
9. Compiling Large Documents: Articles and Reports *(split from previous practical for more depth)*
10. Creating Books and Thesis Documents in LaTeX *(new practical focusing on book-style documents)*
11. Creating Beamer Presentations for Mathematical Talks
12. Troubleshooting LaTeX Errors and Best Practices *(keeps original troubleshooting but with an explicit focus on debugging errors)*

Text Book:

Leslie Lamport, *LaTeX: A Document Preparation System*, Addison-Wesley Publishing Company, 2nd Edition, 1994.

Reference Books:

1. George Grätzer, *More Math Into LaTeX*, Springer Science & Business Media, 2007.
2. Helmut Kopka and Patrick W. Daly, *Guide to LaTeX*, Pearson Education, 2003.
3. Stefan Kottwitz, *LaTeX for Beginners*, Packt Publishing (Open Source).
4. David J. Buerger, *LATEX: For Scientists and Engineers*, McGraw-Hill.
5. Dilip Datta, *LaTeX in 24 Hours: A Practical Guide for Scientific Writing*, Springer.

CO-PO Mapping

Weightage: 1 – weak or low relation, 2 – moderate or partial relation, 3 – strong or direct relation

Programme Outcomes	Course Outcomes						
	CO1	CO2	CO3	CO4	CO5	CO6	CO7
PO01	3	3	3	3	3	3	3
PO02	2	3	3	3	3	3	3
PO03	1	1	2	2	2	2	2
PO04	2	3	3	3	3	3	3
PO05	1	2	3	3	3	3	3
PO06	2	2	2	2	2	3	3
PO07	1	2	2	3	3	3	3
PO08	2	3	3	3	3	3	3
PO09	3	3	3	3	3	3	3
PO10	1	1	1	2	2	2	2
PO11	1	1	1	2	2	2	2
PO12	2	2	2	3	3	3	3
PO13	1	1	1	2	2	2	2

Justification for the mapping

PO1: ***Comprehensive knowledge and understanding*** - LaTeX is a widely used typesetting system, especially in academia. Mastering LaTeX helps students understand structured document preparation, formatting, and presentation of mathematical content, aligning directly with all COs.

PO2: ***Practical, professional, and procedural knowledge*** - Students gain hands-on experience in formatting documents, managing references, creating tables and figures, and structuring large documents. These skills are crucial for professional and academic writing.

PO3: ***Entrepreneurial mindset and knowledge*** **-** LaTeX proficiency can be applied in professional publishing, freelancing, and technical documentation, contributing to an entrepreneurial mindset, though its impact is moderate.

PO4: ***Specialized skills and competencies*** - The ability to create high-quality technical documents, research papers, and presentations using LaTeX is a specialized skill in academia, scientific research, and professional writing.

PO5: ***Capacity for Application, Problem-Solving, and Analytical Reasoning*** - Working with LaTeX requires debugging errors, structuring documents efficiently, and applying logical problem-solving techniques, particularly when dealing with complex documents and equations.

PO6: ***Communication skills and collaboration*** - LaTeX enhances written communication, ensuring clarity in academic and professional documentation. It also facilitates collaboration through tools like Overleaf and version control systems.

PO7: ***Research-related skills*** - LaTeX is an essential tool for research papers, theses, and scientific publications. The ability to manage citations, mathematical typesetting, and structured writing enhances students' research capabilities.

PO8: ***Learning how to learn skills*** - Students learn how to independently explore LaTeX packages, troubleshoot formatting issues, and adapt LaTeX for different document types, fostering self-learning.

PO9: ***Digital and technological skills*** - LaTeX is a digital tool requiring proficiency in command-based formatting, package management, and integration with other software, contributing strongly to digital literacy.

PO10: ***Multicultural competence, inclusive spirit, and empathy*** - While LaTeX itself does not directly contribute to multicultural competence, students may collaborate on international projects, contributing to exposure to global academic standards.
PO11: ***Value inculcation and environmental awareness*** - Digital document preparation reduces paper consumption and promotes sustainable writing practices, aligning with environmental awareness.
PO12: ***Autonomy, responsibility, and accountability*** - Writing structured documents independently requires responsibility, as well as maintaining consistency in citations, references, and formatting.
PO13: ***Community engagement and service*** - Students can share their knowledge by contributing to open-source LaTeX templates, helping others with academic writing, or engaging in collaborative projects that benefit the academic community.

CBCS Syllabus as per NEP 2020 for T.Y.B.Sc. Mathematics (2023 Pattern)

Name of the Programme	: B.Sc. Mathematics
Program Code	: USMT
Class	: T.Y.B.Sc.
Semester	: V
Course Type	: Field Project
Course Name	: Field Project
Course Code	: MAT-335-FP
No. of Teaching Hours	: 60
No. of Credits	: 2

Course Objectives:

1. To provide students with practical exposure to mathematical applications in real-world scenarios.
2. To develop students' ability to identify, analyze, and solve mathematical problems through research and fieldwork.
3. To enhance students' data collection, interpretation, and problem-solving skills using mathematical tools and techniques.
4. To foster independent learning, critical thinking, and creativity in applying mathematical concepts.
5. To enable students to use computational tools, models, and simulations for mathematical problem-solving.
6. To improve students' teamwork, communication, and presentation skills through project-based learning.
7. To encourage interdisciplinary learning by applying mathematics to various fields such as science, economics, and engineering.

Course Outcomes:

CO1: Students will be able to identify and define real-world problems that can be analyzed mathematically.
CO2: Students will be able to apply appropriate mathematical techniques to collect and analyze data.
CO3: Students will be able to develop mathematical models and validate them with real-world applications.
CO4: Students will be able to work collaboratively in a team to investigate and solve mathematical problems.
CO5: Students will be able to use software tools and computational techniques for mathematical computations.
CO6: Students will be able to document their findings effectively in a structured research report.
CO7: Students will be able to present their research findings clearly through oral and visual presentations.

CO-PO Mapping

Weightage: 1 – weak or low relation, 2 – moderate or partial relation, 3 – strong or direct relation

Programme Outcomes	Course Outcomes						
	CO1	CO2	CO3	CO4	CO5	CO6	CO7
PO01	3	3	3	2	2	2	2
PO02	2	3	3	2	3	2	2
PO03	2	2	3	2	2	2	2
PO04	2	3	3	3	3	3	3
PO05	3	3	3	2	3	2	2
PO06	1	2	2	3	2	3	3
PO07	2	3	3	2	3	3	3
PO08	3	3	3	2	3	2	2
PO09	2	3	3	2	3	2	2
PO10	1	1	2	3	1	2	3
PO11	1	1	1	2	1	2	2
PO12	2	2	3	3	2	3	3
PO13	1	1	2	3	1	2	3

Justification for the mapping

PO1: ***Comprehensive knowledge and understanding*** - CO1, CO2, and CO3 have a strong relation as they focus on understanding mathematical concepts and their real-world applications. CO4, CO5, CO6, and CO7 have a moderate relation since they contribute to knowledge but focus more on application and communication.

PO2: ***Practical, professional, and procedural knowledge*** - CO2, CO3, and CO5 have a strong relation as they involve applying mathematical techniques and computational tools. CO1, CO4, CO6, and CO7 have a moderate relation as they support professional skills but are not directly procedural.

PO3: ***Entrepreneurial mindset and knowledge*** **-** CO3 has a strong relation as developing mathematical models is crucial for innovation. CO1, CO2, CO4, CO5, CO6, and CO7 have a moderate relation since mathematical research can inspire entrepreneurship.

PO4: ***Specialized skills and competencies*** - CO2, CO3, CO4, CO5, CO6, and CO7 have a strong relation because they focus on mathematical modeling, problem-solving, teamwork, software tools, and research documentation. CO1 has a moderate relation as problem identification is a prerequisite for skill application.

PO5: ***Capacity for Application, Problem-Solving, and Analytical Reasoning*** - CO1, CO2, and CO3 have a strong relation because they emphasize problem identification, data analysis, and model validation. CO4, CO5, CO6, and CO7 have a moderate relation as they contribute to the application process.

PO6: ***Communication skills and collaboration*** - CO4, CO6, and CO7 have a strong relation as they emphasize teamwork, report writing, and oral presentations. CO2, CO3, and CO5 have a moderate relation because they involve some level of communication through documentation. CO1 has a weak relation as problem identification is largely an individual task.

PO7: ***Research-related skills*** - CO2, CO3, CO5, CO6, and CO7 have a strong relation as they involve research techniques, computational methods, and presentation of findings. CO1 and CO4 have a moderate relation as they provide foundational skills for research.

PO8: ***Learning how to learn skills*** - CO1, CO2, and CO3 have a strong relation as they develop analytical thinking and problem-solving approaches. CO4, CO5, CO6, and CO7 have a moderate relation since they focus on collaborative and technological learning.

PO9: ***Digital and technological skills*** - CO2, CO3, and CO5 have a strong relation as they involve data analysis and computational techniques. CO1, CO4, CO6, and CO7 have a moderate relation since they utilize technology but are not primarily digital-focused.
PO10: ***Multicultural competence, inclusive spirit, and empathy*** - CO4 and CO7 have a strong relation as teamwork and presentations require interaction with diverse perspectives. CO3 has a moderate relation since real-world modeling considers multicultural aspects. CO1, CO2, CO5, and CO6 have a weak relation as they are primarily technical.
PO11: ***Value inculcation and environmental awareness*** - CO4 and CO7 have a moderate relation as teamwork and presentations promote ethical communication. CO1, CO2, CO3, CO5, and CO6 have a weak relation since mathematical problem-solving has limited direct relevance to ethics and environment.
PO12: ***Autonomy, responsibility, and accountability*** - CO3, CO4, CO6, and CO7 have a strong relation as they require independent research, teamwork, and responsibility in presenting findings. CO1, CO2, and CO5 have a moderate relation as they contribute to self-directed learning.
PO13: ***Community engagement and service*** - CO4 and CO7 have a strong relation as teamwork and presentations often involve outreach and engagement. CO3 has a moderate relation since modeling can contribute to societal applications. CO1, CO2, CO5, and CO6 have a weak relation as they are more technical and research-focused.