Programme Outcomes, Programme Specific Outcomes and Course Outcomes of MSc and PhD programmes in Mathematics

Department of Mathematics
Ramakrishna Mission Vivekananda Educational and Research Institute
Belur Math, Howrah, INDIA

Programme Name: MSc Mathematics

Programme Outcomes

- Inculcate critical thinking to carry out scientific investigation objectively without being biased with preconceived notions.
- Equip the student with skills to analyze problems, formulate an hypothesis, evaluate and validate results, and draw reasonable conclusions thereof.
- Prepare students for pursuing research or careers in industry in mathematical sciences and allied fields
- Imbibe effective scientific and/or technical communication in both oral and writing.
- Continue to acquire relevant knowledge and skills appropriate to professional activities and demonstrate highest standards of ethical issues in mathematical sciences.
- Create awareness to become an enlightened citizen with commitment to deliver one's responsibilities within the scope of bestowed rights and privileges.

Programme Specific Outcomes

- Understanding of the fundamental axioms in mathematics and capability of developing ideas based on them.
- Inculcate mathematical reasoning.
- Prepare and motivate students for research studies in mathematics and related fields.
- Provide knowledge of a wide range of mathematical techniques and application of mathematical methods/tools in other scientific and engineering domains.
- Provide advanced knowledge on topics in pure mathematics, empowering the students to pursue higher degrees at reputed academic institutions.
- Strong foundation on algebraic topology and representation theory which have strong links and application in theoretical physics, in particular string theory.
- Good understanding of number theory which can be used in modern online cryptographic technologies.
- Nurture problem solving skills, thinking, creativity through assignments, project work.
- Assist students in preparing (personal guidance, books) for competitive exams e.g. NET, GATE, etc.

Programme Name: PhD Mathematics

Programme Outcomes

Students have/capable of

- Undergone relevant (taught) courses required for undertaking specialized research.
- Identifying unsolved yet relevant problem in a specific field.
- Articulating ideas and strategies for addressing a research problem.
- Undertaken original research on a particular topic.
- Effectively communicating research, through journal publications and conference presentations, to the mathematics community.
- Disseminating research to a broader audience.

Program Specific Outcomes

- Generate publications in reputed mathematical journals.
- Provide scope for interaction with international researchers and developing collaborations.
- Demonstrate the highest standard of ethics in research.
- Provide opportunities to research students for communication (and discussion) of advanced mathematical topics to undergraduate and graduate students.
- Produce next generation researchers in mathematics.

Course Outcomes

SEMESTER—I		
Course Code	Course Name	Course Outcomes
M201	**Algebra 1**	Knowledge gained: • Concept of group action and theorems about group actions. • Structure of permutation groups. • Polynomial rings, EDs, PIDs, & UFDs, and relations among them. • Universality of Polynomial rings Skills gained: • Solving problems using the powerful concept of group action. • Facility in understanding the structure of a problem where the problem involves a permutation group - e.g. nature of the roots of a polynomial equation. • Ability to understand a large class of commutative rings by regarding them as quotients of polynomial rings by suitable ideals. Competency developed: • Applying the concept of a group action to real life problems such as Counting • Facility in handling problems involving polynomial equations • Facility in working with situations involving commutative rings, in particular monogenic algebras of matrices. Implies facility in working with matrices, a concept that finds a large number of applications in real life including the graphs and networks. • Facility in solving real life problems by thinking logically and outside of box.
M202	**Topology**	Knowledge gained: • Topological spaces • Connectedness, compactness, separation axioms • Continuity • Metric spaces review • Fundamental groups • Covering spaces • Computations Skills gained: • Generalization of concepts like continuity • Generalizations of theorems • Distinguishing spaces up to homeomorphisms Competency gained: • Understanding of topological spaces and having a grasp on basic results
M203	**Complex Analysis**	Knowledge gained: • Metric spaces (in particular, the complex plane). • Analytic functions, Cauchy-Riemann differential equations, harmonic functions.

		• Power series, zeros, singularities. • Cauchy's theorem, Cauchy's integral formula, and applications. • Cauchy's residue theorem, and applications. • Mobius transformations. • Riemann mapping theorem. Skills gained: • Differentiation of functions on C, deciding if a function on C is analytic. • Development of functions into power series, classifying singularities. • Integration of functions on C, applications to counting zeros and poles. • Evaluation of indefinite real integrals using complex analysis. • Constructing Mobius transformations mapping given circles to given circles. Competency developed: • Understanding of topological and geometric properties of the complex plane. • Differentiation and integration of functions on C, with applications to problems from real analysis. • Viewing analytic functions as conformal mappings.
M204	**Linear Algebra 1**	Knowledge gained: • Matrix theory, determinants and their application to systems of linear equations. • Eigenvalues, diagonalization of matrices and reduction of systems of linear equations into simpler systems of easily tractable nature. • Vector theory: subspace, basis, linear independence, inner product spaces etc. • Applications of matrix algebra. Skills gained: • Matrix manipulations. • Handing of systems of linear equations. • Use mathematical software to solve problems on linear systems. • Ability to go abstract from concrete: from concrete notion of solution spaces to vector spaces. • Linear modelling problems Competency developed: • Solving Systems of linear equations. • Qualitative analysis of systems of linear equations. • Vector Spaces, linear independence and foundations of abstract algebraic thinking.
M205a	**Real Analysis I**	Knowledge gained: • Basic definition of metric space, norm linear space and inner product space. • Series and sequence of continuous functions. • Equicontinuous families, Arzela-Ascoli Theorem and Stone-Weierstrass Theorem. • Function of several variables and differentiation in Rn. • Inverse and Implicit function Theorem. • Submanifolds of Rn and Rank Theorem.

		Skills gained: • Viewing C[0,1], i.e., the space of continuous functions on [0,1] as a metric space. • The notion of convergence in c[0,1] and related theorems. • Differentiability of functions in several variables and their relation to partial derivatives. • Realising the differentials in terms of geometric properties. Competency developed: • Ability to handle convergence of series and sequence of functions. • Ability to differentiate functions in Rn. • Apply Implicit and inverse function theorem, moving towards calculus on manifolds.
SEMESTER—II		
M205b	**Real Analysis II**	Knowledge gained: • Ordinary differential equations and linear system of o.d.e's. • Cauchy-Peano existence and uniqueness Theorem. • Picard-Lindelof Theorem, Continuation of solutions. • Examples of second-order partial differential equations, i.e., Heat, Wave and Laplace equation. • Properties of Harmonic and subharmonic functions. • Solution to the Dirichlet problem. Skills gained: • Solve ordinary differential equations. • Solve linear system of homogeneous and non-homogeneous o.d.e.s. • Idea about Partial differential equation and link to partial derivatives. • Idea about the solution of the Dirichlet problem for certain subdomains of Rn. Competency developed: • Ability to handle ordinary differential equations and solve them under appropriate assumptions. • Ability to solve a linear system of o.d.e.'s • Apply important properties of harmonic and subharmonic functions. • Apply the solvability of the Dirichlet problem in appropriate conditions.
M206	**Algebra 2 - Fields and Galois Theory**	Knowledge gained: • Solving polynomial equations using formulas for roots • How to test if a polynomial is irreducible Finite Field (Galois Fields) • Understanding which equations can be solved using radials using the conce Skills gained: • Ability to understand/obtain the roots of a polynomial equation if the same has (or can be reduced to) degree less than five. • Facility in working with finite fields • Applying the concept of a field extension to various mathematical problems including geometric constructions and perfect division of a circle into n parts

		Competency developed: • Facility in working with mathematical problems that involve polynomial equations. • Facility in handling problems involving polynomial equations • Applying mathematical methods to the real-life problems including cryptography. • Highly developed reasoning ability.
M207-2	**Theory of Modules**	Knowledge gained: • Module theory as linear algebra over general rings.. • Special classes of modules: free modules, projective modules, flat modules etc. • Theory of modules over PID and its application to Jordan and Rational canonical forms. • Basic concepts in homology: Hom, Tensor etc. Skills gained: • Ability to handle complicated matrices and systems of equations via decomposing into nice forms. • Ability to deal with module theory which is indispensable in wide ranges of mathematical disciplines such as algebra, topology, number theory, operator theory etc. • Ability to handle modern algebraic notions like quotients, generators and relations, universal mapping property etc. • Ability to apply intuitions gained from linear algebra to other seemingly unrelated areas of mathematics. Competency developed: • Deeper insight into and further comfort with linear algebra • Ability to think about classical problems in algebra that involves systems of equations in terms of language of modern algebra. • Basic preparation various research areas in pure mathematics like algebraic geometry, Algebraic Number Theory, Topology etc. • An abstract perspective to many real life problems that can be modelled using linear algebra.
M208	**Measure Theory**	Knowledge gained: • Definition and properties of the exterior measure on R^d. • Measurable sets and Lebesgue measure, construction of non-measurable sets. • Measurable functions. • Lebesgue integration, convergence theorems for Lebesgue integrals and Fubini's theorem. • L^p spaces and Fourier inversion formula. • Connection between differentiation and integration in the context of Lebesgue theory. Skills gained: • Computation of Lebesgue measures. • Establishing measurability or non-measurability of sets and functions. • Approximating measurable functions by simple and step functions. • Computation of Lebesgue integrals, applications to volume calculations and Fourier analysis. • Deciding under which conditions the fundamental theorem of calculus is applicable in the context of Lebesgue integration.

		Competency developed: • Extension of the concepts of measures and integration. • Understanding that Lebesgue integration can solve certain problems for which Riemann integration does not provide adequate answers (in particular, in Fourier analysis). • Viewing differentiation and integration as inverse operations in the more general context of Lebesgue theory, understanding the limitations of this view.
M209	**Elementary Number Theory**	Knowledge gained: • Definitions of divisibility and related algorithms • Basic congruence results • Quadratic reciprocity • Distribution of primes • Basic additive results • Diophantine approximation and transcendental numbers Skills gained: • Solutions of diophantine equations • Arithmetical functions • Distribution of primes Competency developed: • Useful tools in cryptography and related applied subjects
SEMESTER—III		
M211	**Functional Analysis**	Knowledge gained: • Concept of normed linear spaces and inner product spaces. • Concept of bounded linear operators between these spaces. • Concept of the dual space of a normed linear space. • Concept of compact, self-adjoint and normal operators. • Concept of the spectrum of a bounded linear operator. Skills gained: • Using topology to work with infinite dimensional vector spaces. • Using careful analysis to show that certain spaces of functions are complete. • Comparing the differences between finite and infinite dimensional spaces. • Comparing the differences between Banach and Hilbert spaces. • Analysing the structure of the spectrum of certain operators. Competency developed: • Working with a complete orthogonal set a.k.a. Schauder basis in a Hilbert space. • Investigating the best approximation of a given vector by vectors in a given subspace. • Computing the dual spaces of certain Banach spaces. • Working with weak and weak* topologies on normed linear spaces.
M212	**Algebraic Topology**	Knowledge gained: • Concept of homotopy of maps and topological spaces • Concept of chain complexes of abelian groups

		• Concept of homology and cohomology groups of spaces • Exposure to the language of categories and functors Skills gained: • Ability to compute homology groups using long exact sequences • Ability to exercise geometric intuition and visualisation • Ability to translate geometric intuition into rigorous proofs • Working with geometric objects which exist only in higher dimensions Competency developed: • Ability to differentiate between some more topological spaces • Working with homological methods in algebra • Using algebraic methods to solve topological problems • Using topological methods to solve algebraic problems
M213	**Discrete Mathematics**	Knowledge gained: • Basic set theory, cardinal numbers, different concepts of infinity. • Basic combinatorics, induction, inclusion exclusion, pigeon hole principle. • More advance topics in combinatorics: recurrence relations, generating functions, Polya's theorem, graphs, trees, topics in matching such as Marriage theorem. • Ramsey theory, planar graph. • Partially ordered set: Dilworth's theorem and extremal set theory. • Application to real life problems such as network theory, data structure, optimization etc. Skills gained: • Efficiency in handling with discrete structures. • Efficiency in Set theory and handling formal of notions of size. • Efficiency in notions of matching, ordering, planarity. • Efficiency in solving concrete combinatorial problems whose presence is ubiquitous in science and engineering. Competency developed: • Ability to deal with notions of mapping and via that notion ability to tackle various notions of infinity like countable, uncountable etc. • Ability to use graphs as unifying theme for various combinatorial problems. • Ability to apply combinatorial intuitions in network theory, data structure and various other fields of science.
ELECTIVES (SEMESTER—III & IV)		
CS221	**Design and Analysis of Algorithms**	Refer to MSc in Computer Science curriculum CS241
CS244	**Introduction to Optimization Techniques**	Refer to MSc in Computer Science curriculum CS222
AM200	**Nonlinear Dynamics**	Knowledge gained: • Capable of determining fixed points and their stability.

	and Asymptotic Analysis	• Analyze the type of bifurcation. • Ability to draw phase portraits. • Learn the art of asymptotic approximation to challenging mathematical problems. Skills gained: • Knowledge of nonlinear differential equations and their analysis. • Simplify and solve mathematical problems involving small parameters. Competency gained: • Ability to solve complex nonlinear problems. • Asymptotic solutions to complex differential equations.
AM201	**Numerical Algorithms**	Knowledge gained: • Wide variety of numerical techniques to solve mathematical problems arising in diverse scientific contexts. Implementation of stable algorithms for finding roots of nonlinear equations, solving linear system of equations, and solution for ODEs, etc. • Influence of data representation on computers on numerical algorithms. Skill gained: • Implementing numerical algorithms through computer programs. • Analysis of errors of numerical algorithms. Competency gained: • Obtain approximate stable solution to mathematical problems making use of numerical algorithms.
CS312	**Approximation and Online Algorithms**	Refer to MSc in Computer Science curriculum CS312
CS312	**Computing for Data Science**	Refer to MSc in Big Data Analytics curriculum DA100
M308	**Differential Geometry**	• Knowledge of Riemannian manifolds and submanifolds. • Knowledge of operators on forms and integrations, Lie derivative, Stokes theorem, Gauss-Bonnet formula and Index theorem. • Tackle problems on General Relativity, control of non-linear systems, shape analysis.
M313	**Algebraic Geometry**	• Learn topology on projective spaces. • Learn local properties on plane curves. • Solve complex problems on ordinary differential equations. • Tackle problems on CAD/CAM, computer vision.
M322	**Geometric Topology**	• Understanding of Knots and Links, surgery on links. • Knowledge of Hyperbolic geometry groups. • Solve complex problems in topological quantum field theory.
M323	**Lie groups and Lie Algebras**	• Knowledge of Killing form, Lies and Engel's theorem, Universal enveloping algebra and Poincare-Birkhoff-Witt theorem, root space decomposition. • Understanding of Linear Lie group, Lie algebra, Lie transformation groups. • Solving of complex differential equations.
M324	**Advanced Differential Geometry**	• Knowledge of Jacobi Fields, conjugate points, Isometric immersions, Second fundamental form.

		• Knowledge of Bonne-Myers and Synge-Weinstein Theorems, Rauch comparison theorem, Morse Index theorem, Preissman's Theorem, Sphere theorem. • Solve complex problems to diverse problems (in physics, engineering) with differential geometry.
M325	**Complex Manifolds and Riemann Surfaces**	• Learn Cauchy's theorem in several complex variables, Definition and calculus on complex manifolds. • Learn Sheaves and cohomology, Divisors and Line bundles, Normalization theorem. • Applications in string theory.
M 327	**Advanced Algebraic Topology**	• Learn Homotopy groups, Serre spectral sequence. • Learn vector bundles, generalized cohomology theory. • Applications in physics, algebraic geometry.
M332	**Programming and Data Structures**	Refer to MSc in Big Data Analytics curriculum DA101.
M334	**Automata theory, Languages and Computability**	Refer to MSc in Computer Science curriculum CS200.
M341	**Classical Mechanics 1**	Refer to the syllabus of the Physics Department.
M342	**Classical Mechanics 2**	Refer to the syllabus of the Physics Department.
M343	**Quantum Mechanics**	Refer to the syllabus of the Physics Department.
M400	**Project**	• Inculcate a taste for research in Mathematics. • Develop oral and written presentation skills.
M450	**Research Methodology**	• Use of online resources (e.g. MathSciNet) for literature survey. • Preparation of documents using latex software.