GOA UNIVERSITY
Taleigao Plateau, Goa 403 206

REVISED MINUTES

of the 5th Meeting of the Standing Committee of

X ACADEMIC COUNCIL

Day & Date

Tuesday, 14th February, 2023 & Thursday, 23rd February, 2023

Time

10.00 a.m.

Venue
Council Hall,
Administrative Block
Goa University

D 3.3	**Minutes of the Board of Studies in Physics meeting held on 04.11.2022.** The Standing Committee of the Academic Council approved the minutes of the Board of Studies in Physics meeting held on 04.11.2022 with a suggestion to Replace Terminology 'Learning Outcomes' with 'Course Outcomes' **(Action: Assistant Registrar Academic-PG)**
D 3.4	**Minutes of the Board of Studies in Social Work meeting held by circulation.** The Standing Committee of the Academic Council approved the minutes of the Board of Studies in Social Work meeting held by circulation with the following suggestions: 1. Heading for the Courses listed under the structure to be mentioned. (Research Specific Elective Courses and General Elective Courses) 2. Terminology 'Optional Courses' to be replaced with 'Elective Courses'. 3. Terminology 'Recommended readings' to be replaced with 'References/Readings'. 4. Uniform format for the References/Readings to be followed. **(Action: Assistant Registrar Academic-PG)**
D 3.5	**Minutes of the Board of Studies in Public Administration meeting held on 01.07.2022.** The Standing Committee of the Academic Council approved the minutes of the Board of Studies in Public Administration meeting held on 01.07.2022 with the following suggestions: 1. Data Analysis under the content of the syllabus to be added for Course code PATR-501 Qualitative and Quantitative Research Methodology. 2. Heading for the Courses listed under the structure to be mentioned. (Research Specific Elective Courses and General Elective Courses) 3. Course, objectives of PATR-501 - Qualitative and Quantitative Research Methodology to be checked. **(Action: Assistant Registrar Academic-PG)**
D 3.6	**Minutes of the Board of Studies in Mathematics meeting held on 03.11.2022.** The Standing Committee of the Academic Council approved the minutes of the Board of Studies in Mathematics meeting held on 03.11.2022 with the suggestion to verify the title of the Course Code MTTE- 407 as the same Course is offered at UG level. **(Action: Assistant Registrar Academic-PG)**
D 3.7	**Minutes of the Board of Studies in English meeting held on 17.10.2022.** The Standing Committee of the Academic Council approved the minutes of the Board of Studies in English meeting held on 17.10.2022 with the following suggestions: 1. Terminology 'Optional Courses' to be replaced with 'Elective Courses'. 2. Terminology 'Recommended readings' to be replaced with 'References/Readings'.

Std. Com. X AC-5
14.02.2023

GOA UNIVERSITY
Taleigao Plateau, Goa 403 206

F I N A L A G E N D A

For the 5th Meeting of the Standing Committee of

X ACADEMIC COUNCIL

Day & Date

Tuesday, 14th February, 2023

Time

10.00 a.m.

Venue
Conference Hall
Administrative Block
Goa University

D 3.6

Minutes of the Board of Studies in Mathematics meeting held on 03.11.2022.

Part A

1. Recommendations regarding courses of study in the subject or group of subjects at the undergraduate level: Nil
2. **Recommendations regarding courses or group of subjects at postgraduate level:**
   - BoS discussed and finalized the syllabus of Research Specific Elective and Generic Elective courses for semester III and IV. List of these courses and their syllabus is attached as **Annexure I**.**(Refer page No. 263)**
     BoS decided to introduce more Discipline specific electives for Sem 1 and 2. The list of these courses and their syllabi are attached as **Annexure II** **(Refer page No. 285)**.
     It was noticed that the syllabus of one of the Discipline Specific Core papers, MTTC-406 Differential Equations, approved in earlier meeting overlapped significantly with the syllabus of undergraduate paper. Hence it was decided to modify and the syllabus to keep the overlap at a minimum. The new syllabus of this course is attached as **Annexure III** **(Refer page No. 292)**.
   - Syllabus of Research Methodology Course of PhD Mathematics was discussed and approved and the same is attached as **Annexure IV** **(Refer page No. 293)**.

Part B :

1. Scheme of the Examinations at Undergraduate Level: Nil
2. Panel of examiners for different examinations at Undergraduate Level: Nil
3. Scheme of the examinations at post-graduate level:
   BoS discussed the examination scheme for the Postgraduate Diploma in Applied Statistics (offered at Govt. College Sanquelim). It was decided to accept the request of the college to have a continuous evaluation with an ISA component of 40% weightage and SEA component of 60% weightage.
4. Panel of examiners for different examinations at post-graduate Level: Nil

Part C

1. Recommendations regarding preparation and publication and selection of Anthologies in any subject or group of subjects and the names of person recommended for appointment to make the selection: Nil

Part D

1. Recommendations regarding general academic requirements in the Departments of University or affiliated colleges: Nil
2. Recommendation of Academic Audit committee and status thereof: Nil

Part E

(I) Recommendations of text books for the course for study at the Undergraduate level: Nil

(II) Recommendations of text books for the courses of study at the post Graduate level: Nil

Part F

Important points for consideration/approval of Academic Council:

	• MSc Mathematics syllabus for Semester III and IV approved by the BoS. • New Discipline specific elective courses to be offered in Semester I and II and modification of syllabus of one of the discipline specific core courses of Semester II as approved by the BoS. • Research Methodology paper for PhD Mathematics coursework as approved by the BoS. • Examination pattern of Postgraduate Diploma in Applied Statistics as approved by the BoS. The declaration by the Chairman, that the minutes were read out by the Chairman at the meeting itself. Date: 03.11.2022 Sd/- Place: Goa University Signature of Chairman **Part G: The remarks of the Dean of the Faculty.** (I) The minutes are in order. (II) The minutes may be placed before the Academic Council with remarks if any. (III) May be recommended for approval of Academic Council. (IV) Special remarks if any: Nil Date: 03.11.2022 Sd/- Place: Goa University Signature of the Dean **(Back to Index)**
D 3.7	**Minutes of the Board of Studies in English meeting held on 17.10.2022.** **Part A**. i. Recommendations regarding courses of study in the subject or group of subjects at the undergraduate level: NIL ii. Recommendations regarding courses of study in the subject or group of subjects at the postgraduate level: 1. The BoS approved Research Specific Optional Courses and Generic Optional Courses for Semester III & IV from the academic year 2023-24 onwards (**Annexure I Refer page No. 295)** 2. The BoS also prepared Research Methodology Course for PhD students in English (**Annexure II Refer page No.313)** **Part B** i. Scheme of Examinations at undergraduate level: NIL ii. Panel of examiners for different examinations at the undergraduate level: NIL iii. Scheme of Examinations at postgraduate level: iv. Panel of examiners for different examinations at post-graduate level: NIL **Part C.** 1. Recommendations regarding preparation and publication of selection of reading material in the subject or group of subjects and the names of the persons recommended for appointment to make the selection: NIL

D 3.6 Minutes of the Board of Studies in Mathematics meeting held on 03.11.2022.

Annexure I

Goa University

School of Physical and Appl Sciences, MSc Mathematics

Research specific elective and Generic elective PG courses starting from June 2022 onwards

(1) Research Specific Elective Papers

Semester 3 and 4	
Paper Code	**Paper Title**
MTTR-501	Mathematical Modelling (4 Credits)
MTTR-502	Algebraic Topology (4 Credits)
MTTR-503	Number Theory (4 Credits)
MTTR-504	Lie Algebra (4 Credits)
MTTR-505	Graphs and Networks (4 Credits)
MTTR-506	Advanced Graph Theory (4 Credits)
MTTR-507	Measure Theory-I (4 Credits)
MTTR-508	Measure Theory-II (4 Credits)
MTTR-509	Functional Analysis-II (4 Credits)
MTTR-510	Symmetry Methods for Differential Equations (4 Credits)

(2) Generic Elective Papers

Semester 3	
Paper Code	**Paper Title**
MTTG-501	Basic Mathematics for Social Science (4 Credits)
MTTG-502	Operations Research (4 Credits)
MTTG-503	Mathematics for Financial Management and Insurance (4 Credits)
MTTG-504	Mathematics for Financial Market (4 Credits)
MTTG-505	Latex for Mathematics (2 Credits)
MTTG-506	Probability and Statistics (4 Credits)

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M.Sc. Mathematics Research Specific Elective Papers Syllabus (to be implemented from June 2022)

Programme: M.Sc.(Mathematics)
Course Code: MTTR-501
Tittle of the Course: Mathematical Modelling
Number of Credits: 4
Effective from AY:2023-24

Prerequisites: Basic knowledge of Algebra, Differential Equations, Linear Algebra, FEM		
Objective: The objectives of this course are to: • Enable students understand how mathematical models are formulated, solved and interpreted. • Make students appreciate the power and limitations of mathematics in solving practical real-life problems. • Equip students with the basic mathematical modelling skills.		
Content		Hours
Unit I	Simple situations requiring mathematical modelling, techniques of mathematical modelling, classifications, characteristics and limitations of mathematical models, some simple illustrations, mathematical modelling in population dynamics, mathematical modelling of epidemics through systems of ordinary differential equations of first order mathematical models in medicine in terms of systems of ordinary differential equations.	15
Unit II	Mathematical modelling through difference equations, linear growth and decay models.. Population dynamics and genetic and their applications with examples.	30
Unit III	Mathematical Modelling with Graph Theoretical Approach.	15
Pedagogy	Lectures/Tutorials/Self study	
Reference Reading	1. Kapur J. N. Mathematical Modelling, 2nd edition, New Age International, 2015. 2. Meerschaert, M. M. Mathematical Modelling. Academic Press, 2013. 3. Rutherford, A. Mathematical Modelling Techniques. Courier Corporation, 2012. 4. Clive,L. D. Principles of Mathematical Modelling. Elsevier, 2004. 5. Bender, E. A. An Introduction to Mathematical Modelling. Courier Corporation, 2000.	
Learning Outcome	After Completing the course, the student is expected to learn the following:	

	1. Understand what a mathematical model is and explain the series of steps involved in a mathematical modeling process. 2. Use applications of mathematical modeling through difference equations. 3. Understand and apply the concept of mathematical modeling through difference equations in population dynamics, genetics and probability theory. 4. Apply the concept of mathematical modeling through graph theory	

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Programme: M. Sc. (Mathematics)
Course Code: MTTR-502 **Title of the Course:** Algebraic Topology
Number of Credits: 4
Effective from AY: 2023-24

Prerequisites	Point Set Topology, Basic Group Theory	
Objective	To equip students with the skills to study Manifolds using Homotopy and to lay the foundation for a study of Homology Groups.	
Content	**1. The Fundamental group** Homotopy of paths, nulhomotopic, the fundamental group, covering spaces, path lifting, the fundamental group of the circle, retractions and fixed points, Brouwer fixed point theorem for the disc, Fundamental theorem of Algebra, antipode of a point in S^n, Borshuk Ulam theorem, Area Bisection Theorem, Deformation Retracts and homotopy type, Homotopy equivalences and homotopy inverse, Fundamental group of S^n , Fundamental groups of torus, projective plane, fundamental group of double torus is not abelian. **2. The Seifert-van Kampen Theorem** Direct Sums of abelian groups, extension condition, free product of groups, free groups, commutator, commutator subgroup, generators, relations, presentation of groups, finitely presented groups, Seifret-van kampen theorem, fundamental group of a wedge of circles, adjoining a 2-cell, fundamental group of dunce cap. **3. Classification of Covering Spaces** Equivalence of Covering Spaces, General lifting lemma The Universal covering space, Semi-locally simply connected, Existence of Covering Spaces. **4. Classification of Surfaces** Polygonal Region, labeling, Fundamental Groups of Surfaces **Applications to group theory**	20 hours 16 hours 12 hours 12 hours

	Covering Spaces of a graph, The fundamental group of a graph.	
Pedagogy	Lectures/ Tutorials/Assignments/Self-study	
References/ Readings	1. Topology second Edition by James Munkres, Pearson Education 2. Algebraic Topology by Allen Hatcher, Cambridge University Press	
Learning Outcomes	At the end of the course students will be able to • Compute the fundamental groups of manifolds using multiple approaches. • Distinguish between surfaces and other manifolds using the fundamental group. • Formulate and appreciate the general approach of associating commutable Algebraic structures to topological objects so as distinguish between them.	

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Programme: M. Sc. (Mathematics)
Course Code: MTTR-503 **Title of the Course:** Number Theory
Number of Credits: 4
Effective from AY: 2023-24 onwards

Prerequisites for the course:	Some basic Complex Analysis. Elementary number theory. Congruences.	
Objective:	This course will serve as Prerequisites to an advanced Course in Analytical Number Theory.	
Content:	**1. Fundamental Theorem of Arithmetic.** Divisibility. Greatest common divisor. Prime numbers. The Fundamental Theorem of Arithmetic. The series of reciprocals of primes. The Euclidean algorithm. **2. Arithmetical functions and Dirichlet multiplication.** Mobius function μ. Euler totient function $\boldsymbol{\varphi}$. Relation connecting μ and $\boldsymbol{\varphi}$. Product formula for $\boldsymbol{\varphi}$ (n). Dirichlet product of arithmetical functions. Dirichlet inverse and Mobius inversion formula. Mangoldt function. Multiplicative functions. Liouville function. Divisor functions. Generalized convolutions. Formal power series. Bell series. Derivative of arithmetical functions. **3. Averages of arithmetical functions.** Big oh notation. Euler summation formula. Some elementary asymptotic formulas. Average order of d(n). Average order of $\sigma_\alpha(n)$. Average order of $\boldsymbol{\varphi}$ (n). Average order of μ(n) and Λ(n). **4. Some elementary theorems on distribution of prime numbers.** Chebyshev's functions $\vartheta(x)$ and $\psi(x)$. Relations connecting functions $\vartheta(x)$ and $\psi(x)$.	10 hours 12 hours 12 hours 7 hours 7 hours

	5. Characters of finite abelian groups. Characters of finite abelian groups. The character group. The orthogonality relations of characters. Dirichlet character. **6. Partition Theory.** Partitions of numbers. Generating function of p(n). Other generating functions. Theorems of Euler. Theorem of Jacobi. Special cases of Jacobi's identity. **7. Basic Cryptology.** Caesar Cipher. Shift Cipher. Affine cipher. Hill cipher.	10 hours 2 hours
Pedagogy:	lectures/ tutorials/assignments/self-study.	
References/ Readings	1. T. M Apostol, *Introduction to Analuytic Number Theory*, Narosa Publishing House, 1998. 2. Thomas Koshy, *Elementary Number Theroy with Applications*, Second Edition, Elsevier India Pvt. Ltd., **2005**. (Chapter 9) 3. G.H. Hardy and E.M. Wright, Introduction to theory of numbers. (Chapter XIX), Oxford University Press, sixth edition, 2008. 4. Heng Huat Chan, *Analytic Number Theory for Undergraduates*, (Monographs in Number Theory), World Scientific, **2009**. 5. I. Niven, H.S. Zuckerman and H.L. Montgomery, *An Introduction to the Theory of Numbers*, 5th edition, Wiley-India. 6. David Burton, *Elementary Number Theory*, Sixth edition, Tata McGraw-Hill Edition, 2008. 7. A. Baker, A concise introduction to theory of numbers, Cambridge University Press, 2015.	
Learning Outcomes	1.This course prepares the student to learn advanced number theory, Cryptography and Partition theory. 1. Taking this course students can read more advanced Analytic Number Theory books.	

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Programme: M. Sc. (Mathematics)
Course Code: MTTR-504 **Title of the Course:** Lie Algebra
Number of Credits: 4
Effective from AY: 2023-24 onwards

Prerequisites for the course:	Basic Linear Algebra, basic group theory, basic analysis.	
Objective:	This course develops concepts in Matrix Groups and Lie algebras. It helps in understanding other concepts like Manifold, Lie groups etc.	
Content:	1. **Matrix Groups.** Matrices. Real and Complex Matrix Groups. Orthogonal Groups. Topology of Matrix Groups. Tangent space. **2. Lie algebras.** Definition, Some Examples, subalgebras and Ideals. Homomorphisms. Algebras. Derivations. Structure Constants. Ideals and Homomorphisms. Constructions with	12 hours 10 hours

	Ideals. Quotient Algebras. Correspondence between Ideals. Low-Dimensional Lie Algebras. 2. **Solvable Lie Algebras.** Nilpotent Lie Algebras. Subalgebras of gl(V). Nilpotent Maps. Weights. The Invariance Lemma. An Application of the Invariance Lemma. **3. Engel's and Lie's Theorems.** 4. **Some Representation Theory.** Modules for Lie Algebras. Submodules and Factor Modules. Irreducible and Indecomposable Modules. Homomorphisms. Schur's Lemma. Representations of sl(2,C). The Modules V_d . Classifying the Irreducible sl(2,**C**)-Modules. 5. Cartan's Criteria. Testing for Solvability. The Killing Form. Testing for Semisimplicity. Derivations of Semisimple Lie Algebras. The Root Space Decomposition. Cartan Subalgebras. Definition of the Root Space. Decomposition. Cartan Subalgebras as Inner-Product Spaces. Root Systems. Bases for Root Systems. Cartan Matrices and Dynkin Diagrams.	8 hours 6 hours 8 hours 16 hours
Pedagogy:	lectures/ tutorials/assignments/self-study.	
References/ Readings	1. Kristopher Tapp, *Matrix Groups for Undergraduates*, American Mathematical Society, **2005**. 2. Karin Erdmann and Mark J. Wildon, *Introduction to Lie Algebras* , Springer Undergraduate Mathematics Series, Springer-Verlag. **2006**. 3. J.E. Humphreys, *Introduction to Lie algebras and representation theory*, Graduate Text in Mathematics, Springer-Verlag, 1972. 4. N. Jacobson, *Lie Algebras*, Dover Publications, 1962.	
Learning Outcomes	1. Taking this course students get acquainted with Lie algebras and Matrix groups theory. 2. Taking this course student can read Lie groups theory.	

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Programme: M.Sc. (Mathematics)
Course Code: MTTR-505 **Title of the Course:** GRAPHS AND NETWORKS
Number of Credits: 4
Effective from AY:2023-24

Prerequisites	**Basic set theory**	
Objective	Course deals with the basics of graph theory, basic definition of simple graphs, types of graphs, matrix representation of graphs, isomorphism in graphs, Euler & Hamiltonian graphs, trees & their properties, spanning trees, colouring of graphs, independence number and chromatic number of simple graphs, connectivity,	

	cut-set, directed graphs, shortest paths & maximal flows in a network.	
Content	**1. Introduction to graphs** Graphs, subgraphs, operations on graphs, degree sequences, graphic sequences, distance in graphs, walks, trails, paths, circuits, cycles, matrices and isomorphism, complement of graph, bipartite graphs, distance in graphs, digraphs and multidigraphs, Cut-vertices bridges and blocks, classes of graphs, Petersen graphs, regular graphs, Harary graphs. **2. Trees and connectivity** Elementary properties of trees, minimal spanning trees, Prim's algorithm, Kruskal's algorithm, connectivity and edge-connectivity, connectedness of digraphs, Prüfer sequence. **3. Eulerian and Hamiltonian graphs** Eulerian graphs and digraphs, Hamiltonian graphs and digraphs, Fleury's algorithm and Hierholzer's algorithm. **4. Planar graphs** Euler's formula, characterizations of planar graphs, crossing number and thickness. **5. Graph colorings** Vertex colorings, edge colorings, map colourings, Five Color theorem. **6. Matchings and domination in graphs** Matchings and independence in graphs, vertex cover, edge cover, domination number of a graph, independence domination number of a graph. **7. Networks** Relevance of maximum flow, Ford Fulkerson algorithm, Dijkstra's algorithm to find the shortest route.	19 hours 8 hours 7 hours 7 hours 6 hours 6 hours 7 hours
Pedagogy	Lectures/ Tutorials/Assignments/Self-study	
References/ Readings:	1. D. B. West, Introduction to Graph Theory, Prentice Hall of India, 2006. 2. G. Chartrand and L. Lesniak, Graphs and Digraphs, Chapman & Hall/CRC, Third edition, 1996. 3. G. Agnarsson and R. Greenlaw, Graph Theory: Modeling, Applications and algorithms, Pearson, 2011. 4. Gary Chartrand and Ping Zhang, Introduction to Graph Theory, Tata Mc-Graw-Hill Edition, 2006. 5. F. Harary, Graph Theory, Narosa Publishing House, 2001. 6. Gary Chartrand and O.R. Oellermann, Applied Algorithmic Graph Theory, McGraw-Hill Inc. 1993.	
Learning Outcomes:	Learner should be able to tell relevance of graphs in different context, ranging from puzzles & games to social science/engineering/computer science. Problem solving & learning algorithms is also an essential part of graph theory.	

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Programme: M.Sc. (Mathematics)
Course Code: MTTR-506 **Title of the Course:** ADVANCED GRAPH THEORY
Number of Credits: 4
Effective from AY:2023-24

Prerequisites	**Basic Graph Theory**	
Objective	This course will give a deeper insight into basic concepts in Graph Theory, so as to be able to embark into research in the field.	
Content	1. **Review of Basic Concepts:** Graphs, Trees, minimal spanning trees, connectivity and edge-connectivity, Eulerian graphs, Hamiltonian graphs, Euler's formula, Planar graphs, Colourings, Matchings, Independence and Domination in a graph. 2. **Independent Sets and Cliques:** Independent Sets, Cliques, Ramsey Number and Turan's Theorem. 3. **Matchings, Factors and Decompositions:** Matchings & Covers, Maximum Matchings, Matchings in bipartite Graphs, Hall's Matching Condition, Min-Max Theorems, Perfect Matching, Factorizations and Decompositions. 4. **Labelings of Graphs:** Graceful Labeling, Harmonious Labeling, Bandwidth Labeling. **5. Colourability:** Chromatic Number and Chromatic index, Brook's Theorem, Vizing's Theorem, Chromatic Polynomials. **6. Connectivity and Paths:** *k*-Connected Graphs, *k*-Edge Connected Graphs, Menger's Theorem. **7. Domination in Graphs:** Dominating Queens, Dominating Sets in Graphs, Applications of Dominating Sets, Bounds on the Domination Number (in terms of order, in terms of order and size).	7 hours 7 hours 16 hours 8 hours 7 hours 7 hours 8 hours
Pedagogy	Lectures/ Tutorials/Assignments/Self-study	
References/ Readings:	1. G. Chartrand and P. Zhang, Chromatic Graph Theory, CRC Press, 2009. 2. D. B. West, Introduction to Graph Theory, Prentice Hall of India, 2006. 3. T.W. Haynes, S.T. Hedetniemi & P.J. Slater, Fundamentals of Domination in Graphs, Marcel Dekker Inc., 1998. 4. G. Chartrand and L. Lesniak, Graphs and Digraphs, Chapman & Hall/CRC, Third edition, 1996.	
Learning Outcomes:	Learner will be well-equipped with the concepts required to pursue research in Graph Theory.	

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Programme: M.Sc. Mathematics
Course Code: MTTR-507 **Title of the Course: MEASURE THEORY -I**
Number of Credits: 04
Effective from AY:2023-24

Preequisites:	A first course in Real Analysis	
Objectives:	This course gives a thorough introduction to the Lebesgue theory of integration on $\mathbb{R}$ and prepares the students to understand the concepts of abstract measure theory, a fundamental tool of advanced mathematical analysis, probability theory and applications.	
Contents	**1.Reimann-Stieltjes Integral** Weights and measures, The Riemann-Steiltjes integral, Space of integrable functions, Integrators of bounded variation, The Riemann integral. Shortcomings of Riemann integration.	14 hours
	2.Lebesgue Measure on $\mathbb{R}$ The length function and Lebesgue outer measure, Measurable sets, Sigma algebra of measurable sets, Structure of measurable sets, non-measurable sets, idea of abstract measure spaces.	10 hours
	3.Measurable Functions Measurable functions, Extended real valued functions and measurability, Sequence of measurable functions, Egorov's theorem, Approximation of measurable functions	8 hours
	4.The Lebesgue Integral Lebesgue integral of simple functions, non-negative functions and the general case. Chebyshev's inequality, monotone convergence theorem, Fatou's Lemma, Lebesgue dominated convergence theorem, Integral of infinite series of functions. Lebesgue integrability of Riemann integrable functions. Approximation of Lebesgue integrable functions by simple functions, continuous function and step functions.	16 hours
	5. The Lp spaces The L_p-spaces for $1 \leq p \leq \infty$, and their completeness. Approximation of L_p-functions by simple fuctions, continuous functions, step functions	12 hours
Pedagogy	Class room lectures and tutorials, assignments and library reference.	
References	1. Real Analysis, N L Carothers, Cambridge University Press, 2006. 2. Lebesgue Measure and Integration, Murray R. Spiegel Ph.D., Schaum's Outline Series, McGraw Hill Inc., 1990 3.An Introduction to Measure and Integration, Inder K Rana, Narosa, Publishing House, 2005 4. Real Analysis, H.L. Royden, Pearson Education India, 2015 5. Measure Theory and Integration, G. de Barra, New Age International, Pvt.Ltd., 2013	

Learning outcomes	At the completion of this course the student is able to understand and apply the concepts of • Lebesgue outer measure and Lebesgue measure, existence of non-measurable sets • Lebesgue integral as generalization of the Riemann integral and its behaviour with respect to sequence of functions • Basic structure of the L_p-spaces

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Programme: M.Sc. Mathematics
Course Code: MTTR-508 **Title of the Course: MEASURE THEORY-II**
Number of Credits: 04
Effective from AY:2023-24

Prerequisites:	A first course in Real Analysis, Complex Analysis and Topology. A course in Lebesgue measure and integration is desirable	
Objectives:	This course gives a foundation in essential abstract measure theory required in varied aspects of mathematical analysis and its diverse applications	
Contents	**1.Abstract Measure and Integration** The concept of measurability, Borel sets , Measurable functions, Simple functions, Elementary properties of measures, Integration of positive functions, Monotone convergence theorem, Fatou's lemma, Integration of Complex functions, Dominated convergence Theorem, The role played by sets of measure zero, completeness of measure	14 hours
	2.Positive Borel measures Topological Preliminaries -Review of topological notions (without proof) from the theory of locally compact Hausdorff topological spaces-The Urisohn's Lemma. The Riesz representation theorem for $C_c(X)$ where X is locally compact Hausdorff, Regularity properties of Borel measures, the Lebesgue measure on $\mathbb{R}^k$, Continuity properties of measurable functions.	14 hours
	3. L^p -spaces Convex functions and inequalities, Jensen's inequality, The L^p -spaces and their completeness, Approximation by continuous functions- the density of $C_c(X)$ in $L^p(\mu)$.	10 hours
	4.Complex Measures Complex measures, total variation, positive and negative variation, Absolute continuity of measures, The theorem of Lebesgue-Radon-Nikodym, Consequences of the Radon-Nikodym theorem- the polar decomposition and the Hahn decomposition.	12 hours
	5. Integration on Product spaces	10 hours

	Measurabilty on Cartesian products, product measures, The Fubini's theorem, Completion of product measures.	
Pedagogy	Lectures/ Tutorials/Assignments/Self-study	
References	1. Real and Complex Analysis, Walter Rudin, Third Edition, McGrow-Hill Company, 1987 2.Measure Theory and Integration, G.de Barra, Wiley Eastern Limited, 1987 3. Real Analysis, H.L. Royden, Pearson Education India, 2015 4.An Introduction to Measure and Integration, Inder K Rana, Narosa Publishing House, 2013 5.Real Analysis, Gerald B. Folland, John Wiley & Sons, 1984	
Learning Outcomes	After the completion of the course students will be able to understand and apply the concepts in • Abstract measure spaces, measurable sets and measurable functions • Integrals with respect to a measure and their behaviour w.r.t. sequences of functions • Positive Borel measures, Lebesgue measure on $\mathbb{R}^k$ and regularity properties of Borel measure • Abstract L^p-spaces • Complex measures, Radon-Nikodym theorem • Product measure and integration on product spaces.	

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Programme: M.Sc. Mathematics
Course Code: MTTR-509
Title of the Course: Functional Analysis-II
Number of Credits: 4
Effective from AY:2023-24

Prerequisites	A First Course in Real Analysis, Complex Analysis,Topology and Functional Analysis	
Objectives	Having done a first course in Functional Analysis this course develops more advanced concepts in Functional Analysis which introduces the student to some important tools for the applications of Functional Analysis. Further the topics covered in the course form foundations for further readings in Functional Analysis leading to research in diverse branches of Functional Analysis and Operator Theory.	
Contents	**1.Weak and Weak* Topologies** Definitions and properties of weak topology and, weak convergence, Comparison of strong and weak convergences, Definitions and properties of weak* topology and weak*-convergence, comparison of weak and weak* convergences, The Banach- Alaoglu Theorem, Convergence of sequence of Operators -Uniform operator convergence, strong operator convergence, weak	10 hours

	operator convergence-basic properties and the comparison of these convergences.	
	2.Spectral Theory of linear operators in normed spaces Spectral theory in finite dimensional normed spaces, matrix operators and their spectrum, Spectral theory - Basic concepts- Regular value, resolvent set, spectrum and classification of spectrum. Spectral properties of bounded linear operators-spectrum closed, non-empty, spectral radius, resolvent equation, commutativity, spectral mapping theorem for polynomials, linear independence of eigen vectors, Use of complex analysis in spectral theory	12 hours
	3.Compact linear operators on normed spaces Compact operators- definition and basic properties such as continuity, compactness criterion, operators with finite dimensional domain or range, sequence of compact operators, compact operators and weak convergence, separability of the range, adjoint of compact operators, compactness of a product of two compact operators.	12 hours
	4.Spectral properties of compact operators Eigen values countable, characteristic properties of the eigen spaces leading to the direct sum representations of the normed space as a sum of two closed subspaces in terms of a compact operator.	10 hours
	5.Operator equations involving compact linear operators Fredolhm type theorems, Fredolhm alternative, Fredolhm alternative for integral equations	10 hours
	6. Compact self-adjoint operators on Hilbert spaces and their spectrum	6 hours
Pedagogy	Lectures/ Tutorials/Assignments/Self-study	
References	1. Introductory Functional Analysis with Applications, Ervin Kreyszig, John Wiley & Sons, 1978. 2. Functional Analysis (Second Edition), S.Kesavan, Hindustan Book Agency, 2022 3. Functional Analysis, George Bachman and Lawrence Narici, Dover Publications,2000. 4. Functional Analysis, S.Kumaresan and D.Sukumar, Narosa Publishing House, 2020 5. Basic Operator Theory, Israyel Gohberg and Seymour Goldberg, Birkh$\ddot{a}$user, 1981.	
Learning Outcomes	At the completion of this course the student understands and will be able to apply the concepts of • The weak topology and weak*-topology respectively on a normed space and its dual space and their comparisons with	

	the respective norm topologies, weak and weak*-convergences of operators • The Banaach-Aloglu theorm and the characterization of normed spaces • Basics of spectral notions of spectral theory of operators on normed spaces • Spectral properties of compact operators • The Fredplhm alternative

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Programme: M. Sc. (Mathematics)
Course Code: MTTR-510
Title of the Course: Symmetry Methods for Differential Equations
Number of Credits: 4
Effective from AY: 2023-24

Prerequisites	Group theory, Basics of Lie Algebra, Differential equations, Partial Differential equations.	
Objective	The study of ordinary differential equations (ODEs) and partial differential equations (PDEs) is a fundamental subject area of mathematics. Differential equations (DEs) are present in almost all applications of mathematics where they provide a natural mathematical description of phenomena in the physical, natural and social sciences. Symmetry methods systematically extend well known ad-hoc techniques to construct explicit solutions for differential equations, especially for nonlinear DEs. This course is about symmetry methods (group theoretic methods) for solving DEs which is one of the most powerful methods in order to determine particular solutions to DEs.	
Content	1. **Dimensional Analysis, Modeling, and Invariance:** Introduction, Dimensional Analysis, Buckingham Pi Theorem, Application of Dimensional Analysis to DEs. 2. **Lie Groups of Transformations and Infinitesimal Transformations:** Lie Group of Transformations, Infinitesimal Transformations, First Fundamental Theorem of Lie, Infinitesimal Generators, Invariant Functions, Canonical Coordinates, Invariant Surfaces, Invariant Curves, Extended Transformations (Prolongations), Multi-Parameter Lie Groups of Transformations, Lie Algebras, Solvable Lie Algebras. 3. **Ordinary Differential Equations:** Invariance of an ODE, Reduction of Order Via Lie Group of Transformation and Integrating Factors, Mapping of Solutions to Other Solutions, First Order ODEs, Second and Higher Order ODEs, Invariance of ODEs Under Multi-parameter Groups, Applications to Boundary Value Problems	5 Hours 10 Hours 25 Hours

	4. **Partial Differential Equations:** Infinitesimal Criterion for the Invariance of PDEs, Invariance of Scalar PDEs, Invariant Solutions, Mapping of Solutions, Invariance of System of PDEs, Application to Boundary Value Problems.	20 Hours
Pedagogy	Lectures/ Tutorials/Assignments/Self-study	
References/ Readings	1. George W. Bluman and Sukeyuki Kumei, Symmetries and Differential Equations, Springer-Verlag New York, Heidelberg, Berlin, 1989. 2. G. W. Bluman and S. Anco, Symmetries and Integration Methods for Differential Equations; Springer, New York, 2002. 3. G. W. Bluman and J. Cole, Similarity Methods for Differential Equations, Springer-Verlag New York, Heidelberg, Berlin, 1974. 4. Peter J. Olver, Applications of Lie Groups to Differential Equations SpringerVerlag New York, Berlin, Heidelberg, Tokyo, 1979.	
Learning Outcomes	Students will be able to solve non-linear OEs and PDEs using symmetry methods.	

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M.Sc. Mathematics Generic Elective Papers Syllabus (to be implemented from June 2022)

Programme: M.Sc.(Mathematics)
Course Code: MTTG-501
Tittle of the Course: Basic Mathematics for Social Science
Number of Credits: 4
Effective from AY:2023-24

Prerequisites: This course is not recommended for students with Mathematics at UG level.		
Objective: The main objective of this course is to encourage students to develop a working knowledge of the basic Mathematics for social science and will present some of the ideas that form the foundation of quantitative work in the social sciences. In particular, topics from logarithm, set theory, matrix theory and calculus will be discussed with emphasis on the understanding of concepts and the development of intuition		
Content		Hours
Unit I	Binary numbers, indices, logarithm and antilogarithm, laws and properties of logarithms, simple applications of logarithm and antilogarithm, numerical problems on averages, calendar, clock, time, work and distance, mensuration, seating arrangement, sets, types of sets, Venn diagram, De Morgan's laws, problem solving using Venn diagram, relations and types of relations.	15
Unit II	Introduction of sequences, series, AP, GP and HP, relationship between AM, GM and HM. Permutations and combinations. Functions and relations. Types of functions (Polynomial function;	15

	Rational function; Logarithm function, Exponential function; Modulus function; Greatest Integer function), Graphical representation of functions.	
Unit III	Llimit and continuity, derivative as rate measure, differentiation, derivatives of implicit functions using Chain rule. Basic mathematical logic with conditional statements, tautology and contradiction.	10
Unit IV	Random experiment, sample space, events, mutually exclusive events. Independent and dependent Events, law of total probability, Bayes' Theorem. Data on various scales (nominal, ordinal, interval and ratio scale), data representation and visualization, data interpretation (dispersion, deviation, variance, skewness and kurtosis), percentile rank and quartile rank, correlation (Pearson and Spearman method of correlation), linear regression, applications of descriptive statistics using real time data.	20
Pedagogy	Lectures/Tutorials/Self study	
Reference Reading	Gill J. Essential Mathematics for Political and Social Research, Cambridge University Press, 2016. 2. Haeussler E., Paul R. and Wood R. Introductory Mathematical Analysis for Business, Economics, and the Life and Social Sciences, 15th edition. Prentice-Hall, 2015. 3. Goldstein L., Lay D., and Schneider D. Calculus and Its Applications, 14th Edition. Prentice Hall, 2014. 4. Hagle T. Basic Math for Social Scientists: Problems and Solutions, 1996. 5. Hagle T. Basic Math for Social Scientists: Concepts, 1996. 6. Kleppner D. and Ramsey N. Quick Calculus. Wiley, 1995. 7. Namboodiri K. Matrix Algebra: An Introduction. Sage Publications # 38, 1994.	
Learning Outcome	After Completing the course, the student is expected to learn the following: 1. Explain the fundamental concepts of indices, logarithm and antilogarithm and their role in basic Mathematics for social science. 2. Demonstrate accurate and efficient use of set theory and Venn diagram. 3. Understand and use the terms: function, relation, series arithmetic, geometric progression, Permutations and Combinations. 4. Understand the concepts and properties of limits, continuity and differentiation of a function, logical reasoning, probability and descriptive statistics	

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Programme: M.Sc.(Mathematics)
Course Code: MTTG-502
Tittle of the Course: Operations Research

Number of Credits: 4
Effective from AY:2023-24

Prerequisites: Not recommended for mathematics students		
Objective: This course is designed to introduce basic optimization techniques in order to get best results from a set of several possible solutions of different problems viz. linear programming problems, transportation problem, assignment problem and unconstrained and constrained problems etc.		
Content		Hours
Unit I	Linear programming: formulation and solution of linear programming problems by graphical, simplex methods, Big-M, degeneracy, duality in linear programming, sensitivity analysis	15
Unit II	Transportation problems: basic feasible solutions, optimum solution by stepping stone and modified distribution methods, unbalanced and degenerate problems, transhipment problem. Assignment problems: solution by Hungarian method, unbalanced problem, case of maximization, travelling salesman and crew assignment problems.	15
Unit III	Queuing theory: basic components of a queuing system, general birth-death equations, steady-state solution of Markovian queuing models with single and multiple servers (M/M/1. M/M/C, M/M/1/k, M/M/C/k)	15
Unit IV	Game theory: two persons zero sum game, game with saddle points, rule of dominance; algebraic, graphical and linear programming, concept of mixed strategy. sequencing problems: processing of n jobs through 2 machines, n jobs through 3 machines, 2 jobs through m machines, n jobs through m machines.	15
Pedagogy	Lectures/Tutorials/Self study	
Reference Reading	1. Sharma, S. D. Operation Research, Kedar Nath Ram Nath Publications, 2012. 2. Swarup, K. and Gupta, P.K. Operations Research. S. Chand publisher, 2010. 3. Taha, H. A. Operation Research: An Introduction.9th edition, Pearson, 2010. 4. Gupta, P.K. and Hira, D.S. Introduction to Operations Research, S. Chand & Co. 2008. 5. Sharma, J. K., Mathematical Model in Operation Research, Tata McGraw Hill, 1989. 6. Hagle T. Basic Math for Social Scientists: Problems and Solutions, 1996.	
Learning Outcome	After Completing the course, the student is expected to learn the following:	

	1. Understand linear programming problems and to find their solutions by using different method. 2. Find optimal solution of transportation problems and assignment problems 3. Understand and solve different queuing models. Find optimal solution of linear programming model using Game Theory. Also learn about sequencing problems.	

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Programme: M.Sc.(Mathematics)
Course Code: MTTG-503
Tittle of the Course: Mathematics for Financial Management and Insurance
Number of Credits: 4
Effective from AY: 2023-24

Prerequisites: Basic knowledge of, Differential Equations, Linear Algebra, Numerical Methods		
Objective: This course introduces the basic concepts of Financial Management such as Insurance and Measurement of returns under uncertainty situations. The philosophy of this course is that Time value of Money - Interest rate and discount rate play a fundamental role in Life Insurance Mathematics – Construction of Morality Tables.		
Content		Hours
Unit I	Financial Management –overview. Nature and scope of financial management. Goals and main decisions of financial management. Difference between risk, Speculation and gambling. Time value of Money - Interest rate and discount rate. Present value and future value discrete case as well as continuous compounding case. Annuities and its kinds.	15
Unit II	Meaning of return. Return as Internal Rate of Return (IRR). Numerical methods like Newton Raphson method to calculate IRR. Measurement of returns under uncertainty situations. Meaning of risk. Difference between risk and uncertainty. Types of risks. Measurements of risk. Calculation of security and Portfolio Risk and Return-Markowitz Model. Sharpe Single Index ModelSystematic Risk and Unsystematic Risk.	15
Unit III	Taylor series and Bond Valuation. Calculation of Duration and Convexity of bonds. Insurance Fundamentals – Insurance defined. Meaning of loss. Chances of loss, Peril, Hazard, proximate cause in insurance. Costs and benefits of insurance to the society and branches of insurance-life insurance and various types of general insurance. Insurable	15

	loss exposures- feature of a loss that is ideal for insurance.	
Unit IV	Life Insurance Mathematics – Construction of Morality Tables. Computation of Premium of Life Insurance for a fixed duration and for the whole life. Determination of claims for General Insurance – Using Poisson Distribution and Negative Binomial Distribution –the Polya Case. Determination of the amount of Claims of General Insurance – Compound Aggregate claim model and its properties, Claims of reinsurance. Calculation of a compound claim density function F, Recursive and approximate formulae for F	15
Pedagogy	Lectures/Tutorials/Self study	
Reference Reading	1. Ross, S. M. An Introduction to Mathematical Finance. Cambridge University Press, 2019. 2. Elliott, R. J. and Kopp, P. E. Mathematics of Financial Markets. Sprigner Verlag, New York Inc, 2018. 3. Damodaran, A. Corporate Finance - Theory and Practice. John Wiley & Sons, Inc, 2012. 4. Hull, J. C. Options, Futures, and Other Derivatives. Prentice-Hall of India Private Ltd, 2010. 5. Daykin, C. D., Pentikainen, T. and Pesonen, M. Practical Risk Theory for Actuaries. Chapman & Hall, 2008. 6. Dorfman, M. S. Introduction to Risk Management and Insurance. Prentice Hall, Englwood Cliffs, New Jersey, 1999. 7. Neftci, S. N. An Introduction to the Mathematics of Financial Derivatives. Academic Press, Inc,1991	
Learning Outcome	After Completing the course, the student is expected to learn the following: 1. Demonstrate knowledge of the terminology related to nature, scope, goals, risks and decisions of financial management. 2. Predict various types of returns and risks in investments and take necessary protective measures for minimizing the risk. 3. Develop ability to understand, analyze and solve problems in bonds, finance and insurance.	

	4. Build skills for computation of premium of life insurance and claims for general insurance using probability distributions.	

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Programme: M. Sc. (Mathematics)
Course Code: MTTG-504 **Title of the Course:** Mathematics for Financial Market
Number of Credits: 4
Effective from AY: 2023-24

Prerequisites	Elementary Calculus, Basic Probability Theory	
Objective	At the end of this course the student will gain knowledge of basic concepts in financial mathematics	
Content	**1. Introduction: A Simple Market Model** Basic Notions and Assumptions, No-Arbitrage Principle, One-Step Binomial Model, Risk and Return, Forward Contracts, Call and Put Options, Managing Risk with Options **2. Risk-Free Assets** Time Value of Money, Money Market **3. Risky Assets** Dynamics of Stock Prices, Binomial Tree Model **4. Discrete Time Market Models** Stock and Money Market Models, Extended Models **5. Portfolio Management** Risk, Two Securities, Several Securities, Capital Asset Pricing Model **6. Forward and Futures Contracts** Forward Contracts, Futures **7. Options: General Properties** Definitions, Put-Call Parity, Bounds on Option Prices, Variables Determining Option Prices, Time Value of Options **8. Option Pricing** European Options in the Binomial Tree Model, American Options in the Binomial Tree Model, Black-Scholes Formula	6 Hours 6 Hours 6 Hours 6 Hours 12 Hours 6 Hours 10 Hours 8 Hours
Pedagogy	Lectures/ Tutorials/Assignments/Self-Study	
References/ Readings	1. Marek Capinski and Tomasz Zastawniak, Mathematics for Finance, An Introduction to Financial Engineering, Springer, 2003 2. Sheldon M. Ross, An Elementary Introduction to Mathematical Finance, Cambridge University Press, 2011	
Learning Outcomes	At the end of this course students will be able to 1. Recall and explain concepts in simple market models, risk free assets, risky assets, dynamics of stock prices, portfolio management, forward contracts, futures contracts and options. 2. Prove important theorems related to topics studied.	

	3. Apply knowledge gained to solve basic mathematical problems in finance.	

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Programme: M. Sc. (Mathematics)
Course Code: MTTG-505 **Title of the Course: Latex for Mathematics**
Number of Credits: 2
Effective from AY: 2023-24

Prerequisites	Basic ability to type, Comfort with mathematical symbols and notations.	
Objective	At the end of this course the student will develop the required skill set to typeset mathematical research and produce professional mathematical documents with vector graphics. The student will also be able to effectively use macros in LATEX	
Content	**1. LATEX Basics:** A Bit of History, Basics, LATEX input files, Input File Structure, A Typical Command Line Session, Logical Structure of your Document, Packages, The Structure of Text and Language, Files you might Encounter **2. Real World LATEX:** Line Breaking and PageBreaking, Ready-Made Strings, Dashes and Hyphens, Slash, Ellipsis, Ligatures, Abstract, Simple Commands,The Space Between Words, Titles, Chapters, and Sections, Cross References, Footnotes, Lists, Non-Justified Text,Quotations, Code Listings, Tables, Including Graphics and Images, Floating Bodies, Big Projects **3. Typesetting Mathematical Formulae:** Modern Mathematics, Single Equations, Building Blocks for Mathematical Formulae, Multiline Equations, Units, Matrices and the Like, Spacing in Math mode, Theorems and Proofs, Fiddling with math styles, Dots, More about Fractions **4. Bibliographies:** the bibliography environment, biblatex with biber Database files,Using biblatex,Controlling the bibliography,Citing commands, More about entries. **5. Specialities:** Indexing, Installing Extra Packages, LATEXand PDF, Creating Presentations **6. Graphics in Your Document:** Overview, Basic Usage, Curves and Shapes, Customizing Paths and Nodes, Coordinates, Reusing Pictures, Libraries **7. Customising LATEX:** New Commands, Environments and Packages, Fonts and Sizes, Custom Fonts with fontspec, Colours, Lengths and Spacing, The Layout of the Document, Fancy Headers	8 Hours 8 Hours 8 Hours 4 Hours 4 Hours 12 Hours 16 Hours

Pedagogy	Lectures/ Tutorials/Assignments/Self-study	
References/ Readings	1. Tobias Oetiker, Marcin Serwin, Hubert Partl, Irene Hyna and Elisabeth Schlegl, The Not So Short Introduction to LATEX, 2022 2. George Gratzer, More Math Into LATEX, Springer, 2016 3. Leslie Lamport, A Documentation Preparation System LATEX User's Guide and Reference Manual, Pearson, 2006	
Learning Outcomes	1. Gain the required knowledge to type professional mathematical documents and prepare presentations. 2. Apply graphics packages to create produce vector graphics in mathematical documents. 3. Design customized mathematical documents to suit individual needs with effective use of Fonts, Colours etc.	

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Programme: MSc Mathematics
Course Code: MTTG-506 **Title of the Course: Probability and Statistics**
Number of Credits: 4
Effective from AY: 2023-24

Prerequisites for the course:	Basic Mathematics	
Objective:	The aim of course is to familiarize students with the fundamental concepts & techniques in Probability theory and Statistical analysis.	
Content:	**1. Data Handling:** Tabulation and frequency distribution, relative frequency distribution, cumulative frequency distribution, **2. Measures of central tendency & dispersion:** Arithmetic mean, Median, Mode for raw data, grouped data, relationship between mean, median and mode, quartiles deciles, percentiles. Variability, range, mean deviation, coefficient of mean deviation, standard deviation, variance, coefficient of variance, skewness, Karl Pearson's coefficient, Bowley's coefficient. **3. Various Concepts in Probability Theory:** Sample spaces, events, permutations and combinations, axioms of probability, conditional probability, independence and multiplication rule, Baye's Theorem. **4. Discrete Distributions:** Random variables, discrete probability densities, cumulative distribution, expectation, variance and standard deviation. Binomial, Geometric and Poisson distributions. **5. Continuous Distributions:** Continuous densities, cumulative distribution and distribution parameters, uniform, normal, standard normal,	03 hours 07 hours 05 hours 09 hours 10 hours

	Gamma, exponential and Chi-squared distributions. Normal approximation to binomial distribution. 04 hours **6. Descriptive Statistics and Estimation:** Random sampling, sample statistics, point estimation, sampling distribution of a statistic, distribution of the sample mean and the Central Limit Theorem. 08 hours 7. **Statistical Inference**: determining sample size, estimation of mean and proportions, Student-t distribution, confidence interval, hypothesis testing on the mean and proportion, type I, type II errors, power of the test, Z-test, t-test, F-test. 08 hours **8. Simple linear regression and correlation:** Linear regression analysis, model and parameter estimation by least-squares method, Properties of least square estimators, confidence interval estimation and hypothesis testing, Pearson's correlation coefficient, covariance, coefficient of determination. 06 hours **9. Other tests:** ANOVA, non-parametric tests, Chi-square tests.	
Pedagogy:	Lectures/Tutorials/Assignments/Self-study	
References/Readings	1. Devore, J. L.: Probability & Statistics for Engineering and the Sciences, 8th edition, Cengage Learning, 2012. 2. Milton, J. S. and Arnold J. C.: Introduction to Probability and Statistics: Principles and Applications for Engineering and the Computing Sciences, 4th edition, Tata McGraw-Hill, 2007. 3. Prem S. Mann: Introductory Statistics, eighth edition, John Wiley & Sons, 2012. 4. Joseph K. Blitzstein and Jessica Hwang: Introduction to Probability, CRC Press 2014. 5. R.J. Barlow, Statistics: A Guide to the Use of Statistical Methods in the Physical Sciences, Wiley, 1989. 6. F. James, Statistical Methods in Experimental Physics, 2nd ed., World Scientific, 2006. 7. Probability and Statistics in Experimental Physics, Byron P. Roe, 2nd ed., Springer, 2001. 8. Fundamentals of Statistical and Thermal Physics, F. Reif, McGraw Hill, Inc. 1965	
Learning Outcomes:	1. The students will get familiarized with basic properties of random variables, probability distributions. 2. The students will be able to understand basic concepts in Statistics, how to collect, arrange, present, summarize and analyze statistical data, arrive at statistical inferences, apply appropriate statistical tests and interpret its results.	

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Annexure II

Goa University

School of Physical and Appl Sciences, MSc Mathematics

Additional Discipline Specific elective PG courses starting from June 2022 onwards

Semester 1 and 2	
Paper Code	**Paper Title**
MTTE-406	Finite Element Method (4 Credits)
MTTE-407	Combinatorics (4 Credits)
MTTE-408	Computational Mathematics using Python (2 Credits)
MTTE-409	Elementary Number Theory (2 Credits)
MTTE-410	Discrete Mathematical Structures (4 Credits)

Programme: M.Sc.(Mathematics)
Course Code: MTTE-406
Tittle of the Course: Finite Element Methods
Number of Credits: 4
Effective from AY:2023-24

Prerequisites: Basic knowledge of Algebra, Differential Equations, Linear Algebra		
Objective: The course aims to provide the fundamental concepts of the element method mainly including shape functions and general linear and higher order elements up to 3 dimensions. The course objective is to acquaint the students about application of finite element methods for solving various boundary value problems		
Content		Hours
Unit I	General theory of finite element methods, difference between finite element and finite difference methods, review of some integral formulae, concept of discretization, different coordinates, one dimensional finite elements,	15
Unit II	Numerical integration, construction of shape functions: linear elements (one dimensional bar element, two dimensional-triangular element)	15
Unit III	Higher order elements: one dimensional quadratic element, two dimensional triangular element, rectangular element.	15
Unit IV	Weighted residual and variational approaches (Galerkin method, collocation method, Rayleigh Ritz method etc.), solving one-dimensional problems. Application of finite element methods for solving various boundary value problems.	15
Pedagogy	Lectures/Tutorials/Self study	
Reference Reading	1. Rao, S. S. The Finite Element Method in Engineering. 5 th edition, Butterworth-Heinemann, 2017.	

	2. Hughes, T. J. R. The Finite Element Method (Linear Static and Dynamic Finite Element Analysis). Courier Corporation, 2007. 3. Zienkiewicz, O. C. and Taylor, R. L. The Finite Element Method: The Basis. Butterworth-Heinemann, 2000. 4. Smith, G. D. Numerical solution of Partial Differential Equations: Finite difference methods. Oxford Applied Mathematics and Computing Science Series, 1985.	
Learning Outcome	After Completing the course, the student is expected to learn the following: 1. Understand the general theory of Finite Element method and its difference with finite difference method 2. Use the role and significance of shape functions in finite element formulations and use of linear, quadratic, and cubic shape functions for interpolation 3. Formulate some important 1, 2 and 3 dimensional elements 4. Apply the weighted residual and variational approaches in solving some boundary value problems	

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Programme: M. Sc. (Mathematics)
Course Code: MTTE-407 **Title of the Course: COMBINATORICS**
Number of Credits: 4
Effective from AY: 2022-23

Prerequisites	Basics of - Set Theory , Algebra, Linear Algebra	
Objectives	Starting from the basic principles of counting, this course aims to give an introductory exposition to different aspects of Combinatorics. The course will emphasise on the importance of enumeration tools and techniques in diverse branches of Mathematics and applied fields.	
Content	**1.Basic Counting Principles and Techniques** Review of basic Counting Principles-Addition Principle, Multiplication Principle, Method of two-way Counting, Method of Bijections, Permutations and Combinations, Circular Permutations, Counting Objects with Repetitions, Binomial and Multinomial Theorems (Combinatorial Proofs), Binomial and Multinomial Coefficients and Identities.	12
	2.The Fundamental Counting Problem Statement of the Problem-The Sxteen Cases, Partition Numbers P(n,k) and P(n), Stirling Numbers S(n,k) and s(n,k), Bell numbers B(n).	2
	3.Recurrence Relations and Explicit Formulas	12

	The Inclusion-Exclusion Principle, Derangements and D(n), Recurrence Relations and Explicit Formulas for P(n,k),P(n), S(n,k), s(n,k), B(n), and D(n). Idea of Generating Functions , Method of solving Linear Recurrence Relations Using Generating Functions, Generating Functions for P(n,k), P(n), S(n,k), s(n,k), B(n) and D(n).	
	4.Pigeonhole Principle (PHP) The Pigeonhoe Principle - its different formulations and examples, Applications of PHP to some standard Problems in Geometry, Number Theory , Graph Theory and Colouring of Plane.	6
	5.Sequnces and Partial Orders Applications of PHP to Sequences and Partial Orders- The Erdös-Szekeres Theorem, Dilworth's Lemma, Dilworth's Theorem, Sperner's Theorem.	6
	6.Ramsey Theory Ramsey's Theorem –First version (for 2 colours) , Second version (for r colours), and Infinitary version, Ramsey Numbers and bounds, Computations of small Ramsey Numbers, Schur's Theorem, van der Waerden's Theorem (Statement and Discussion).	10
	7. Polya's Theory of Counting Group actions on sets, Burside's Lemma, Labelings, Cycle indexes, computation of cycle indexes of standard groups, Polya's theorem and examples.	12
Pedagogy	Lectures/ Tutorials/Assignments/Self-study	
References	1. Introduction to Combinatorics, Martin J. Erickson, John Wiley,1996. 2. Cominatorial Techniques, Sharad S. Sane, Hindustan Book Agency, 2013. 3. Introducion to Combinatorics, W.D. Wallis and J.C. George, 2011. 4. A Walk Through Combinatorics, M. Bona, World Scientific Publishing Company, 2002. 5. Combinatorics, V.K. Balakrishnan, Schaum Series, McGraw-Hill,	
Learning Outcomes	Students ,on completion of this course, (i) Will be able to appreciate the importance of combinatorial techniques in diverse branches of Mathematics and Applied fields. (ii) This course will teach the students how to understand and deal with enumerative problems and to apply combinatorial techniques to solve a range of application problems in Optimization, Graph Theory and Networking.	

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Programme: M. Sc. (Mathematics)
Course Code: MTTE-408 **Title of the Course:** Computational Mathematics using Python
Number of Credits: 2
Effective from AY: 2023-24

Prerequisites	This course assumes that the student has done an undergraduate course of Numerical Methods and Matrix Algebra using Python Programming. Basic Number Theory, Algebra, Linear Algebra, Graph Theory and Differential equations.	
Objective	To equip students with the skills of python programming which aid the study and understanding of Mathematics.	
Content	**1. Introduction to Python (Review)** IDLE (Installation in Windows/Linux), Python strings, Relational Operators, Logical Operators, Precedence of Operators, Variables and assignment statements, Keywords, Script mode.	4 hours
	2. Functions (Review) Built-in functions*; input, eval, composition, print, type, round, min, max, pow* Type conversion, Random number generation; *randint* Functions from *math* module, complete list of Built-in functions using help and dir Function Definition and call, fruitful and void functions, function help, default parameter values, keyword arguments Importing User-defined modules, Assert statement.	6 hours
	3. Control Structures (Review) General form of *if* , *if-else* , *if-elif-else* conditional statement Nested *if-elif-else* conditional statement. *For* and *While* statements and their comparison, Nested loops, *Break, Continue, Pass* statements *Else statement* associated with a For/While statement Testing, Debugging	4 hours
	4. Scope of Variables/Names Objects and Object ids, Namespaces; Global and Local variables, LEGB Rule	2 hours
	5. Strings Slicing, membership, basic functions and methods on strings.	2 hours
	6. Mutable and Immutable Objects Lists, functions and methods on lists, List comprehension, copying lists, Sets, functions and methods on sets, Tuples, functions and methods on tuples, Dictionary, dictionary operations, functions.	8 hours
	7. Recursion Iterative Approach and recursive approach,	

	Program to find Minors and Determinant of a matrix. **8. Files and Exceptions** File handling, writing structures to a file, exceptions **9. Classes and Objects** Class attributes, class variables, destructor, Person, Graphs: as an example of a class, Highest degree and least degree, operator overloading, instance method, static method, composition and inheritance. **10. Graphics** 2D graphics, mathplotlib, matplotlib installation, points, lines. **11. Algorithms to be implemented in Python**** i. Expressing the elements of the Symmetric group as a product of disjoint cycles. ii. Characteristic Equation of a nxn matrix. Synthetic Division to find rational roots of a polynomial when rational roots exist. iii. Row Reduction to (Reduced)Row Echelon form. Generating nxn Identity Matrix Inverse of a matrix using row reduction iv. Finding Basis for the Row Space, Column Space of a matrix A and solution space of AX=B. v. Single step and multi-step Methods vi. Dijkstra's Algorithm to find shortest path. vii. Kruskal's Algorithm to find minimum spanning tree viii. Havel and Hakimi's Algorithm for degree sequences. ix. Welsh and Powell algorithm for graph coloring x. Fitting of straight line and quadratic curve to given data xi. Solutions of linear Diaphontine Equations **Any 7 of these algorithms should be implemented.	4 hours 4 hours 8 hours 4 hours 14 hours
Pedagogy	Laboratory Sessions/Assignments/Self-study	
References/ Readings	1. Python Programming: A modular approach by Sheetal Taneja and Naveen Kumar, Pearson Education, 2020. 2. Python Programming: Beginner to Pro by Michael Urban, Mike Murach Publishing, 2016.	
Learning Outcomes	At the end of the course students will be able to • Create programs to implement computational mathematical algorithms. • Create classes of mathematical objects and be able to randomly generate instances for testing formulas.	

	• Create simple 2D graphics in python	

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Programme: M. Sc. (Mathematics)
Course Code: MTTE-409 **Title of the Course: Elementary Number Theory**
Number of Credits: 2
Effective from AY: 2023-24

Prerequisites	A basic course in Number Theory	
Objective	At the end of this course the student will gain basic knowledge of primitive roots, quadratic reciprocity and continued fractions	
Content	**1. PRIMITIVE ROOTS AND INDICES:** The order of an integer modulo n, Primitive Roots for Primes, Composite numbers having primitive roots, The theory of indices **2. THE QUADRATIC RECIPROCITY LAW:** Euler's criterion, the Legendre symbol and its properties, Quadratic reciprocity, Quadratic congruences with composite moduli **3. NUMBERS OF SPECIAL FORM:** Marine Mersenne, Perfect numbers, Mersenne primes and amicable numbers, Fermat numbers **4. REPRESENTATION OF INTEGERS AS SUMS OF SQUARES:** Sums of two squares, Sums of more than two squares **5. CONTINUED FRACTIONS:** Finite continued fractions, Infinite continued fractions, Farey fractions, Pell's equa-tion	4 Hours 6 Hours 4 Hours 4 Hours 12 Hours
Pedagogy	Lectures/ Tutorials/Assignments/Self-study	
References/ Readings	1. David M. Burton, Elementary Number Theory, Mc Graw Hill, 2017 2. Kenneth H Rosen, Elementary Number Theory, Pearson, 2015	
Learning Outcomes	1. Be able to recollect the various definitions and theorems in Primitive Roots, Quadratic Reciprocity and Continued Fractions. 2. Apply the results in the course to solve problems.	

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Programme: M. Sc. (Mathematics)
Course Code: MTTE-410 **Title of the Course:** Discrete Mathematical Structures

Number of Credits: 4
Effective from AY: 2023-24

Prerequisites	Sets and functions	
Objective	To equip students with the skills and techniques of discrete structures like graphs and trees	
Content	1. Recurrence relations, linear recurrence relations with constant co-efficients, homogeneous solutions, particular solutions, total solution, solution by method of generating functions. 2. Graphs, isomorphism, complement, multipartite, degree sequences, distance, eccentricity, centre, periphery, eulerian and hamiltonian graphs, algorithm for shortest path in a graph, planar graphs. **3.** Cut-vertices, bridges, blocks, non-seperable, trees, forests, $\kappa(G)$, $\kappa_1(G)$, branch, chord, fundamental cycle, fundamental edge cut, minimum spanning tree, kruskal's algorithm. 4. Transport Networks, capacity, flow, cut, Maximum flow and finding maximum flow 5. Vertex and edge coloring, domination number, independent domination number	6 hours 20 hours 14 hours 4 hours 16 hours
Pedagogy	Lectures/ Tutorials/Assignments/Self-study	
References/ Readings	1. Elements of Discrete Mathematics, C L Liu, Tata McGraw Hill, Special Indian Edition 2008 2. Graphs and Digraphs, Chartrand and Lesniak, Chapman & Hall/CRC Fourth edition, 2005	
Learning Outcomes	At the end of the course students will be able to • Solve linear recurrence relations. • Apply results of graph theory to solve problems modeled using graphs • Compile a logical argument to prove simple results involving graphs.	

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Annexure III

Goa University
School of Physical and Appl Sciences,
MSc Mathematics

Modified Discipline Specific Core PG course starting from June 2022 onwards

Programme: M.Sc. Mathematics

Course Code: MTTC-406 Title of the Course: DIFFERENTIAL EQUATIONS

Number of Credits: 04

Effective from: June, 2022.

Prerequisites	Knowledge of basic Real Analysis, Linear Algebra and Differential equations.	
Objectives	This course develops the ability to understand the qualitative theory and some properties of solution of differential equations.	
Contents	1.Review of linear differential equations of the first and higher order. Linear differential equations with constant and variable coefficients. Exact equations, Wronskian, Separable equations, Euler's equation, reduction of order of equation, variation of parameters, Abel's Formula.	10 hours
	3. Existence and uniqueness of solutions of first order differential equation. Lipschitz condition, Picard's successive approximation method, Gronwall's type integral inequality. Continuation of Solution and dependence on initial conditions. Non local existence of solution.	16 hours
	4. Systems of Linear differential equations. Existence and Uniqueness of solutions. Vector matrix form. Linear system with Constant and variable coefficients. Fundamental matrix, matrix exp, and repeated eigenvalue. Non homogeneous linear systems and variation of parameters. Conversion of nth order equation to system of first order.	22 hours
	5. Self-adjoint second order differential equation. Sturm Liouville Problem. Greens functions. Picard's theorem. Zeros of solutions. Comparison Theorems. Linear oscillations. Oscillations of $x''(t) + a(t)x(t) = 0$.	12 hours
Pedagogy	Lectures/ tutorials/assignments/self-study	
References	[1] .Deo S.G.; Raghvendra V.; RasmitaKar, Lakshmikantham V. : Text book of Ordinary Differential equations, 3rd edition, Tata McGraw Hill, New Delhi 2015. [2] . E.A. Coddington; An introduction to Ordinary Differential Equations, Prentice Hall,India,2003. [3]. Kelly W. Patterson A.C. : Theory of Differential Equations, Springer, 2010 [4]. Simmons G.F.; Differential Equations with Historical Notes, Tata M H., 2017	
Learning Outcomes	Students will learn to solve system of ordinary differential equations and to analyse the properties of solution.	

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Annexure IV

Goa University

School of Physical and Appl Sciences, PhD Mathematics

Research Methodology Paper for PhD coursework

Programme: Ph.D (Mathematics)

Course Code: **Title of the Course: Research Methodology**

Number of Credits: 4

Effective from AY: 2022-23

Prerequisites for the course:	M.Sc. in Mathematics	
Objective:	The aim of course is to orient Pre-PhD students towards research by introducing them to research methodology.	
Content:	**UNIT I: BASICS OF RESEARCH** History of Mathematics, Overview of scientific research, Understanding research methodology in Mathematics, Strategies for investigating problems, Tactics for solving problems, Literature survey and critical review of the topic and a problem, Selection of a research topic, Formulating the research problem, Studying and reviewing a paper, Designing the research, Structure and components of scientific reports – Types of reports – Technical reports and thesis – Significance – Different steps in the preparation – Layout, structure and language of typical reports, Importance of effective communication. **UNIT II: MATHEMATICAL SOFTWARE** Knowledge of SageMath/Scilab/Python/R/MATLAB/Mathematica for: Plotting 2D and 3D Graphs, Programming, Handling Computational Calculus, Algebra and Linear Algebra, Solving Differential Equations. **UNIT III: TYPESETTING AND PRESENTATION USING LATEX** Basics – Line Breaking and Page Breaking, Ready-Made Strings, Dashes and Hyphens, Slash, Ellipsis, Ligatures, Abstract, Simple Commands, The Space Between Words, Titles, Chapters, and Sections, Page Customization, Page Numbering. Typesetting Mathematical Formulae – Modern Mathematics, Single Equations, Building Blocks for Mathematical Formulae, Multiline Equations, Units, Matrices and Determinants, Spacing in Math mode, Theorems and Proofs. Bibliographies – Bibliography environment, biblatex with biber Database files, Cross Referencing, Using biblatex, Controlling the bibliography, Citing commands, Generating Table of Contents.	20 Hours 15 Hours 20 Hours

	Graphics – Overview, Basic Usage, Curves and Shapes, Customizing Paths and Nodes, Coordinates, Reusing Pictures, Creating Tables, Libraries. Customising LaTeX – New Commands, Environments and Packages, Fonts and Sizes, Custom Fonts with fontspec, Colours, Lengths and Spacing, The Layout of the Document, Fancy Headers. Presentation Tools and Skills – Beamer as a tool for paper and thesis presentations, Oral and poster presentations. **UNIT IV: FUNDING** Writing a research proposal, Proposal vs Report, Funding agencies, Types of research grants.	5 Hours
Pedagogy:	Reading/Discussion/Assignments/Presentations	
References/ Readings	1. Mathematics and its History, John Stillwell, Springer, 2012. 2. The Art and Craft of Problem Solving, Paul Zeitz, John Wiley & Sons, 2019. 3. How to Solve It – a new aspect of mathematical method, G. Polya, Princeton University Press, 2014. 4. C. George Thomas, "Research Methodology and Scientific Writing", Springer, 2021. 5. Computational Mathematics with SageMath, Paul Zimmermann, Society for Industrial & Applied Mathematics, 2018. 6. Tobias Oetiker, Marcin Serwin, Hubert Partl, Irene Hyna and Elisabeth Schlegl, Latex in 157 minutes: The Not So Short Introduction to Latex, Samurai Media Limited, 2015.	
Learning Outcomes:	1. The students will exhibit higher maturity in terms of designing and developing their research work by critically planning, executing, and defending their research. 2. The student will learn to effectively use Mathematical software for various computations. 3. The students will appreciate and discover more of LaTeX. 4. The students will be made aware on writing research projects and seeking financial assistance from various avenues.	

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