SIKKIM UNIVERSITY

(A Central University Established by an Act of Parliament of India, 2007)

LEARNING OUTCOME - BASED CURRICULUM

P.HD. IN MATHEMATICS

(With effect from Academic Session 2023-24)

DEPARTMENT OF MATHEMATICS

SIKKIM UNIVERISTY

6TH MILE, TADONG - 737102

GANGTOK, SIKKIM, INDIA

Preamble

Mathematics PhD coursework aims to equip students with essential mathematical skills and knowledge in the chosen research fields, as well as the ability to conduct original research in the field. Students are expected to complete coursework in any areas in pure or applied mathematics. The Mathematics PhD program provides students an opportunity to establish a career in mathematics through engagement in rigorous study and research in one of the most fundamental and important areas of science and technology.

Programme Learning Outcomes

PLO1 Advanced Theoretical Proficiency: Develop a deep understanding of advanced mathematical theories, concepts, and techniques across various branches of mathematics, such as algebra, analysis, geometry, and topology.

PLO2 Research Skills: Acquire the ability to critically analyse and evaluate existing mathematical literature, identify research gaps, and propose and conduct original research in mathematics.

PLO3 Problem-solving ability: Enhance problem-solving skills by applying mathematical theories, including the formulation and analysis of mathematical theory that addresses complex and interdisciplinary challenges.

PLO4 Communication and Presentation: Cultivate effective communication skills to articulate complex mathematical ideas both in written form (research papers, reports) and oral presentations (seminars, conferences) to both specialized and non-specialized audiences.

PLO5 Collaboration and Interdisciplinary Awareness: Foster the ability to collaborate with peers, mentors, and researchers from different mathematical disciplines and related fields, promoting interdisciplinary research and understanding the role of mathematics in broader scientific endeavours.

Coursework Structure

Total Credits: 14

Structure of the curriculum

Course Code	Course category	Number of courses	Credits per course	Total credits
MAT-C-701	C: Research Methodology	1	4	04
MAT-C-702	C: Research and Publication Ethics	1	2	02
MAT-R-703	C: Research Proposal and Preparation	1	4	04
MAT- E-7XX	E: Elective Paper	1	4	04
	Total Credits			14

List of elective courses for PhD coursework

Course Name	Course Code
Computational Methods for the PDE	MAT-E-701
Commutative Rings	MAT-E-702
Value Distribution Theory	MAT-E-703
Advanced Linear Algebra	MAT-E-704
Advanced Functional Analysis	MAT-E-705
Numerical Linear Algebra	MAT- E-706
Mathematical and Computational Biology	MAT- E-707
Graphs and Matrices	MAT- E-708
Homological Algebra	MAT- E-709

Detailed Syllabus

Name of the Programme: PhD Coursework Course Code: MAT-C-701 Name of the Course: Research Methodology			
Course Credits		**No. of Hours per Week**	**Total No. of Teaching Hours**
4 Credits		4 hrs	60 Hrs
Course Learning Outcomes (CLOs)		1. Understand the fundamental concepts and principles of research methodology in mathematics. 2. Identify and formulate research questions and hypotheses. 3. Evaluate and critique scientific literature. 4. Communicate research findings effectively through written articles and oral presentations. 5. Apply ethical guidelines and practices in scientific research	
Unit	**Unit Title**	**Contents**	
I	Introduction to Research Methodology	Meaning and importance of research, Types of research (basic, applied, and action research), Steps in the research process (problem identification, literature review, hypothesis formulation, data collection, analysis, and interpretation, and report writing), Literature review: types, sources, and techniques for conducting literature review in mathematics research, Writing literature reviews: synthesis, critical analysis, and citation management software (e.g., Mendeley, EndNote)	
II	Research Techniques in Mathematics	Mathematical problems: formulation, analysis, and interpretation, Visualization methods; Writing research proposals: components, structure, and guidelines; Writing research papers: organization, style, and formatting (e.g., LaTeX); Presenting research: conferences, seminars, posters, and oral presentations; Responding to reviewers and revising manuscripts; Career planning and academic publishing: journals, book chapters, and monographs.	
III	Mathematical methods	ODEs and PDEs; Numerical methods; Modeling and simulation; Mathematical analysis tools and techniques; matrix algebra and computation.	
IV	Mathematical software tools	Symbolic calculation software; plotting and visualization software; modeling and simulation software; coding languages.	

Suggested-teaching learning strategy

1. Lecture with interactive discussions and problem-solving activities.
2. Assignments and individual presentations.
3. Student-led classroom teaching.
4. Group discussions.

Assessment Framework

Modes	**Written**	**Oral**	**Integrated**
Formative (50 Marks)	Class Test, Open Book Test, Quiz, Online Test, Class Assignment, Home Assignment	Oral Test, Viva-Voce, Seminar	Presentation, Seminars
Summative (50 marks)	End-Semester Examination conducted by the University		

Note: The course teacher may select an appropriate mode of formative assessment based on the nature of the Course Learning Outcomes (CLOs) and its practicality.

Suggested Readings

- Bird, A.(2006). Philosophy of Science.Routledge
- Maclntyre, Alasdair (1967) A Short History of Ethics. London
- P.Chaddah, (2018) Ethics in Competitive Research: Do not get Scooped; do not get Plagiarized, ISBN :978-9387480865
- National Academy of Sciences, National Academy of Engineering and Institute of Medicine. (2009). On Being a Scientist: A Guide to responsible conduct in Research: Third Edition, National Academies Press.
- Resnik, D.B.(2011) What is ethics in research & why is it important. National institute of Environmental Health Science, 1-10 Retrieved from https://www.niehs.nih.gov/research/resources/bioethics/whatis/index.cfm
- Beall, J: (2012) Predatory publishers are corrupting open access. Nature, 489(7415), 179-179.
- Indian National Science Academy (INSA), Ethics in Science Education, Research and Governance (2019), ISBN:978-81-939482-1-7. htt://www.insaindia.res.in/pdf/Ethics_Book.pdf.

Note**: Latest edition of text books and reference books may be used.**

Name of the Programme: PhD Coursework
Course Code: MAT-C-702
Name of the Course: Research and Publication Ethics

Course Credits	**No. of Hours per Week**	**Total No. of Teaching Hours**
2 Credits	2 hrs	30 Hrs

Course Learning Outcomes (CLOs)	1. Understand the fundamental ethical principles and guidelines governing research and publication. 2. Identify and address ethical challenges and dilemmas that may arise during the research process. 3. Demonstrate knowledge of responsible conduct of research and research integrity. 4. Understand the importance of data management, privacy, and confidentiality in research. 5. Apply ethical guidelines to the process of authorship, acknowledgments, and peer review. 6. Recognize and manage conflicts of interest in research and publication. 7. Develop strategies for promoting ethical behavior and fostering a culture of research integrity

Unit	**Unit Title**	**Contents**
I	**Philosophy and Ethics**	• Introduction to Philosophy: definition, nature and Scope, Concept, Branches. • Ethics: definition, moral philosophy, nature of moral judgments and reaction.
II	**Scientific Conduct**	• Ethics with respect to science and research. • Intellectual honesty and research integrity. • Scientific misconducts: Falsification, Fabrication, and Plagiarism (FFP). • Redundant publications: duplicate and overlapping publications, salami slicing. • Selective reporting and misrepresentation of data.
III	**Publication Ethics**	• Publication ethics: definition, introduction and importance • Best practices /Standards setting initiatives and guidelines: COPE. WAME, etc. • Conflicts of interest • Publication misconduct: definition, concept, problems that lead to unethical behaviour and vice-versa, types • Violation of publication ethics, authorship and contributor ship • Identification of publication misconduct, complaints and appeals • Predatory publishers and journals

IV	**Practice**	**OPEN ACCESS PUBLISHING** • Open access publications and initiatives • SHERPA/RoMEO online resource to check publisher copyright & Self – archiving policies • Software tool to identify predatory publications developed by SPPU • Journal finder /Journal suggestion tools viz. JANE, Elsevier journal finder, Springer Journal Suggester, etc. **PUBLICATION MISCONDUCT** *A. Group Discussions* • Subject specific ethical issues, FFP, authorship • Conflicts of interest • Complaints and appeals: examples and fraud from India and abroad *B. Software tools* Use of plagiarism software like Turnitin, Urkund and other open-source software tools **DATABASES AND RESEARCH METRICS** *A. Databases* • Indexing databases • Citation databases: Web of Science, Scopus, etc. *B. Research Metrics* • Impact Factor of Journal as per Journal Citation Report, SNIP, SJR, IPP, Cite Score • Metrics: h-index, g index, i10 index, altmetrics

Suggested-teaching learning strategy

1. Lecture with interactive discussions and problem-solving activities.
2. Assignments and individual presentations.
3. Student-led classroom teaching.
4. Group discussions.

Assessment Framework

Modes	**Written**	**Oral**	**Integrated**
Formative (50 Marks)	Class Test, Open Book Test, Quiz, Online Test, Class Assignment, Home Assignment	Oral Test, Viva-Voce, Seminar	Presentation, Seminars
Summative (50 marks)	End-Semester Examination conducted by the University		

Note: The course teacher may select an appropriate mode of formative assessment based on the nature of the Course Learning Outcomes (CLOs) and its practicality.

Suggested Readings

- Bird, A. (2006). Philosophy of Science. Routledge
- Maclntyre, Alasdair (1967). A Short History of Ethics. London
- P. Chaddah, (2018). Ethics in Competitive Research: Do not get Scooped; do not get Plagiarized, ISBN :978-9387480865
- National Academy of Sciences, National Academy of Engineering (US) and Institute of Medicine (US) Committee on Science, Engineering, and Public Policy. (2009). *On Being a Scientist: A Guide to Responsible Conduct in Research*. National Academies Press (US).
- Resnik, D.B. (2011). What is ethics in research & why is it important. *National institute of Environmental Health Science*, 1-10 Retrieved from: https://www.niehs.nih.gov/research/resources/bioethics/whatis/index.cfm
- Beall, J. (2012). Predatory publishers are corrupting open access. Nature, 489(7415), 179-179. https://doi.org/10.1038/489179a
- Indian National Science Academy (INSA), (2019). Ethics in Science Education, Research and Governance. ISBN: 978-81-939482-1-7. http://www.insaindia.res.in/pdf/Ethics_Book.pdf

Note**: Latest edition of text books and reference books may be used.**

Name of the Programme: PhD Coursework Course Code: MAT-R-703 Name of the Course: Research Proposal and Preparation		
Course Credits	**No. of Hours per Week**	**Total No. of Teaching Hours**
4 Credits	4 hrs	60 Hrs
Course Learning Outcomes (CLOs)	1. Critically evaluate and present recently published scientific research studies. 2. Identify research gaps and formulate research questions. 3. Conduct a comprehensive review of literature on a specific topic of interest. 4. Develop a detailed research proposal incorporating the literature review. 5. Present their research proposal effectively in a seminar setting. 6. Enhance their oral communication and presentation skills. 7. Strengthen their understanding of research methodology and scientific writing.	
It combines classroom lectures and personal guidance or simply rely on supervision.		

Assessment Framework

Modes	Written	Oral	Integrated
Formative (50 Marks)	Research proposal writing	Viva-Voce, Seminar	Presentation, Seminars
Summative (50 marks)	Seminar		

Note: The course teacher may select an appropriate mode of formative assessment based on the nature of the Course Learning Outcomes (CLOs) and its practicality.

List of elective courses for PhD coursework

Name of the Programme: PhD coursework Course Code: MAT-E-701; Name of the Course: Computational Methods for the PDE			
Course Credits		**No. of Hours per Week**	**Total No. of Teaching Hours**
4 Credits		L/T/P: 3+1+0 hrs	60 Hrs
Course Learning Outcomes (CLOs)		After completion of the course students will be: 1. Able to take more advanced courses in PDE and its applications. 2. Able to solve problems on PDEs 3. Understand the basic results. 4. Able to apply it to solve problems in other fields.	
Unit	**Unit Title**	**Contents**	
I	Partial Differential Equations	Introduction, Difference methods, Routh Hurwitz Criterion, Domain of dependence of hyperbolic equations.	
II	Difference methods in Parabolic PDEs	Introduction, One space dimension, Two space dimensions, variable coefficients problems, spherical and cylindrical coordinate systems.	
III	Difference methods for hyperbolic PDEs	Introduction, One space dimension, Two space dimensions, first order equations, systems of first order equations	
IV	Numerical methods	Difference methods for linear BVPs, General second order linear equations, quasilinear	

	for elliptic PDEs	elliptic equations

Skill Developments Activities: *(These activities are only indicative; the Faculty member can innovate)*

- Problem solving.
- Group discussions.
- Application to other fields.

Suggested-teaching learning strategy

1. Lecture with interactive discussions and problem-solving activities.
2. Assignments and individual presentations.
3. Student-led classroom teaching.
4. Group discussions.

Assessment Framework

Modes	**Written**	**Oral**	**Integrated**
Formative (50 Marks)	Class Test, Open Book Test, Quiz, Online Test, Class Assignment, Home Assignment	Oral Test, Viva-Voce, Seminar	Presentation, Seminars
Summative (50 marks)	End-Semester Examination conducted by the University		

Note: The course teacher may select an appropriate mode of formative assessment based on the nature of the Course Learning Outcomes (CLOs) and its practicality.

Suggested Readings

- "Numerical Solution of Partial Differential Equations: Finite Difference Methods" by G. D. Smith, published in 2015 by Oxford University Press.
- "Finite Element Methods for Computational Fluid Dynamics: A Practical Guide" by R. D. Fox and A. T. McDonald, published in 2003 by CRC Press.
- "Numerical Solution of Partial Differential Equations by the Finite Element Method" by C. Johnson, published in 1987 by Cambridge University Press.
- "Numerical Recipes: The Art of Scientific Computing" by W. H. Press, S. A. Teukolsky, W. T. Vetterling, and B. P. Flannery, published in 2007 by Cambridge University Press.
- "Introduction to Finite Element Analysis and Design" by N. S. Rao, published in 2009 by John Wiley & Sons.

Note**: Latest edition of text books and reference books may be used.**

Name of the Programme: PhD coursework **Course Code: MAT-E-702; Name of the Course: Commutative Rings**			
Course Credits		**No. of Hours per Week**	**Total No. of Teaching Hours**
4 Credits		L/T/P: 3+1+0 hrs	60 Hrs
Course Learning Outcomes (CLOs)		After completion of the course students will be: 1. Able to take more advanced courses in ring theory. 2. Able to solve various problems. 3. Understand the basic results. 4. Able to apply it to solve problems in other fields.	
Unit	**Unit Title**	**Contents**	
I	Prime Ideals and applications	Prime ideals, G-domains, G-ideals, Hilbert rings, Hilbert Nullstellensatz.	
II	Localization and Integral Extension	Localization, Prime ideals in polynomial rings,Integralextensions,Going-up and Going-down theorems, Valuation domains, Prufer domains and Bezout domains.	

III	Noetherian Rings & Factorization	Noetherian rings, Hilbert basis theorem, Krull's intersection theorem, Nakayama lemma, Zero divisors, Discrete valuation rings, Dedekind domains, Krull domains.
IV	Cohen Macaulay & Regular Rings	R-sequences, Cohen-Macaulay rings, Principal ideal theorem, Generalised principal ideal theorem, Regular rings.

Skill Developments Activities: *(These activities are only indicative; the Faculty member can innovate)*

- Problem solving.
- Group discussions.
- Application to other fields.
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Suggested-teaching learning strategy

1. Lecture with interactive discussions and problem-solving activities.
2. Assignments and individual presentations.
3. Student-led classroom teaching.
4. Group discussions.

Assessment Framework

Modes	**Written**	**Oral**	**Integrated**
Formative (50 Marks)	Class Test, Open Book Test, Quiz, Online Test, Class Assignment, Home Assignment	Oral Test, Viva-Voce, Seminar	Presentation, Seminars
Summative (50 marks)	End-Semester Examination conducted by the University		

Note: The course teacher may select an appropriate mode of formative assessment based on the nature of the Course Learning Outcomes (CLOs) and its practicality.

Suggested Readings

- Commutative Rings by Irving Kaplansky, Chicago universitypress,1968.
- Commutative Ring Theory by Hideyuki Matsumura, Cambridge studies in advanced mathematics 8, Cambridge university press, Cambridge,1989.
- Introduction to Commutative Algebra by M.F.AtiyahandI.G. Macdonald, Addison- Wesley Publ. Company, 1969.
- Local Algebra by Jean-Pierre Serre (translated from theFrench by CheeWhye Chin), Springer,1999.

Note**: Latest edition of text books and reference books may be used.**

Name of the Programme: PhD coursework
Course Code: MAT-E-703; Name of the Course: Value Distribution Theory

Course Credits	**No. of Hours per Week**	**Total No. of Teaching Hours**
4 Credits	L/T/P: 3+1+0 hrs	60 Hrs

Course Learning Outcomes (CLOs)		After completion of the course students will be: 1. Able to take more advanced courses in Complex Analysis. 2. Able to solve problems of the subjects 3. Understand the basic results. 4. Able to apply it to solve problems in other fields.
Unit	**Unit Title**	**Contents**
I	Review of general theory of entire and	Harmonic functions and their relations with analytic functions, Poisson-Jensen's formula, Elliptic function, Nevanlinna's characteristic function and related results.

	meromorphic functions	
II	Growth properties of entire and meromorphic functions	Growth indicators of functions, order, hyper-order, basic properties and related results.
III	Deficiencies of meromorphic functions and their generalizations	Various types of deficiencies of different functions at some given point, their inter-relations and relevant results.
IV	Uniqueness of entire and meromorphic functions sharing values	Basic uniqueness theorems on analytic functions and their counterparts for meromorphic functions, value sharing, uniqueness results under value sharing.

Skill Developments Activities: *(These activities are only indicative; the Faculty member can innovate)*

- Problem solving.
- Group discussions.
- Application to other fields.
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Suggested-teaching learning strategy

1. Lecture with interactive discussions and problem-solving activities.
2. Assignments and individual presentations.
3. Student-led classroom teaching.
4. Group discussions.

Assessment Framework

Modes	**Written**	**Oral**	**Integrated**
Formative (50 Marks)	Class Test, Open Book Test, Quiz, Online Test, Class Assignment, Home Assignment	Oral Test, Viva-Voce, Seminar	Presentation, Seminars
Summative (50 marks)	End-Semester Examination conducted by the University		

Note: The course teacher may select an appropriate mode of formative assessment based on the nature of the Course Learning Outcomes (CLOs) and its practicality.

Suggested Readings

- W. K. Hayman: Meromorphic Functions, The Clarendon Press, Oxford, (1964).
- C. C. Yang and H. X. Yi: Uniqueness Theory of Meromorphic Functions, Science Press, Beijing (2003).
- A. I. Markushevich, Theory of Functions of a Complex Variable, (Vol. I, II, III).
- A. S. B. Holland: Introduction to the theory of Entire Functions, Academic Press, New York (1973).

Note**: Latest edition of text books and reference books may be used.**

Name of the Programme: PhD coursework Course Code: MAT-E-704; Name of the Course: Advanced Linear Algebra			
Course Credits		**No. of Hours per Week**	**Total No. of Teaching Hours**
4 Credits		L/T/P: 3+1+0 hrs	60 Hrs
Course Learning Outcomes (CLOs)		After completion of the course students will be: 1. Able to take more advanced courses in linear algebra. 2. Able to solve problems. 3. Understand the basic results. 4. Able to apply it to solve problems in other fields.	
Unit	**Unit Title**	**Contents**	
I	Eigenvalues, Eigenvectors and Canonical forms	Eigenvalues and eigenvectors, diagonalization, invariant subspaces and triangularization, minimal polynomial, Jordan canonical form with applications, rational canonical form.	
II	Inner Product Spaces	Hermitian, normal and unitary matrices, Schur's theorem - real and complex versions. Spectral theorems for normal and Hermitian matrices - real and complex versions. Positive definite matrices, characterizations of definiteness. Congruence and simultaneous diagonalization. Singular value decomposition, polar decomposition.	
III	Hermitian and Symmetric Matrices	Variational characterizations of eigenvalues of Hermitian matrices, Rayleigh-Ritz theorem, Courant-Fischer theorem, Weyl theorem, Cauchy interlacing theorem, Inertia and congruence, Sylvester's law of inertia.	
IV	Localization and perturbation of eigenvalues	Matrix norms, spectral radius formula, relationships between matrix norms. Gerschgorin discs, perturbation theorems and other inclusion regions. Functions of matrices via spectral decompositions.	

Skill Developments Activities: *(These activities are only indicative; the Faculty member can innovate)*

- Problem solving.
- Group discussions.
- Application to other fields.
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Suggested-teaching learning strategy

1. Lecture with interactive discussions and problem-solving activities.
2. Assignments and individual presentations.
3. Student-led classroom teaching.
4. Group discussions.

Assessment Framework

Modes	**Written**	**Oral**	**Integrated**
Formative (50 Marks)	Class Test, Open Book Test, Quiz, Online Test, Class Assignment, Home Assignment	Oral Test, Viva-Voce, Seminar	Presentation, Seminars
Summative (50 marks)	End-Semester Examination conducted by the University		

Note: The course teacher may select an appropriate mode of formative assessment based on the nature of the Course Learning Outcomes (CLOs) and its practicality.

Suggested Readings

- R. A. Horn and C. R. Johnson, Matrix Analysis, CUP, 1985.
- S. Axler, Linear Algebra Done Right, 2nd Edition, UTM, Springer, Indian Edition, 2010.
- P. Lancaster and M. Tismenetsky, The Theory of Matrices, Second edition, Academic Press, 1985.
- F. R. Gantmacher, The Theory of Matrices, Vol-I, Chelsea, 1959.

Note**: Latest edition of text books and reference books may be used.**

Name of the Programme: PhD coursework **Course Code: MAT-E-705; Name of the Course: Advanced Functional Analysis**			
Course Credits		**No. of Hours per Week**	**Total No. of Teaching Hours**
4 Credits		L/T/P: 3+1+0 hrs	60 Hrs
Course Learning Outcomes (CLOs)		After completion of the course students will be: 1. Able to take more advanced courses in analysis. 2. Able to solve problems. 3. Understand the basic results. 4. Able to apply it to solve problems in other fields.	
Unit	**Unit Title**	**Contents**	
I	Bounded linear operators on Banach spaces	Banach spaces, bounded linear operators, open mapping theorem, closed graph theorem, uniform boundedness principle.	
II	Weak and weak* topologies	Dual spaces, Hahn-Banach theorem, transpose of a bounded linear operator, weak and weak* topologies, Alaoglu theorem.	
III	Bounded operators on Hilbert spaces	Hilbert spaces, orthonormal bases, Riesz representation theorem. Adjoint of a bounded linear operator, orthogonal projection, projection theorem, self-adjoint, normal and unitary operators.	
IV	Spectral Theory	Spectrum of a bounded linear operator, Gelfand-Mazur Theorem, Compact operators, Riesz theory for compact operators, spectral theory of compact self-adjoint/normal operators.	

Skill Developments Activities: *(These activities are only indicative; the Faculty member can innovate)*

- Problem solving.
- Group discussions.
- Application to other fields.
-

Suggested-teaching learning strategy

1. Lecture with interactive discussions and problem-solving activities.
2. Assignments and individual presentations.
3. Student-led classroom teaching.
4. Group discussions.

Assessment Framework

Modes	**Written**	**Oral**	**Integrated**
Formative (50 Marks)	Class Test, Open Book Test, Quiz, Online Test, Class Assignment, Home Assignment	Oral Test, Viva-Voce, Seminar	Presentation, Seminars

Summative (50 marks)	End-Semester Examination conducted by the University

Note: The course teacher may select an appropriate mode of formative assessment based on the nature of the Course Learning Outcomes (CLOs) and its practicality.

Suggested Readings

- J. B. Conway: A Course in Functional Analysis, 2nd edition (Springer low price edition)
- B. V. Limaye: Functional Analysis, 3rd edition (New Age Publishers)
- G.F. Simmons: Introduction to Topology and Modern Analysis (McGraw Hill Education)

Note**: Latest edition of text books and reference books may be used.**

Name of the Programme: PhD coursework
Course Code: MAT-E-706; Name of the Course: Numerical Linear Algebra

Course Credits	**No. of Hours per Week**	**Total No. of Teaching Hours**
4 Credits	L/T/P: 3+1+0 hrs	60 Hrs

Course Learning Outcomes (CLOs)		After completion of the course students will be: 1. Able to take more advanced courses in linear algebra. 2. Able to solve problems. 3. Understand the basic results. 4. Able to apply it to solve problems in other fields.
Unit	**Unit Title**	**Contents**
I	Linear systems	LU decompositions, Gaussian elimination with partial pivoting, banded systems, positive definite systems, Cholesky decomposition.
II	Sensitivity of Linear Systems	Floating point computations, IEEE floating point arithmetic, analysis of roundoff errors; Sensitivity analysis linear and condition numbers, sensitivity analysis of linear systems, stability of Gaussian elimination.
III	The Least Squares Problem	Householder transformation, Givens rotations; QR factorization, stability of QR factorization. Solution of linear least squares problems, normal equations, singular value decomposition (SVD), Moore-Penrose inverse. Sensitivity analysis of least-squares problems.
IV	Eigenvalue Problems	Eigenvalues, eigenvectors, Schur decomposition, reduction to Hessenberg and tridiagonal forms. Power, inverse power and Rayleigh quotient iterations. Explicit and implicit QR algorithms for symmetric and nonsymmetric matrices, sensitivity analysis of eigenvalues. Reduction to bidiagonal form, Golub- Kahan algorithm for computing SVD.

Skill Developments Activities: *(These activities are only indicative; the Faculty member can innovate)*

- Problem solving.
- Group discussions.
- Application to other fields.
-

Suggested-teaching learning strategy

1. Lecture with interactive discussions and problem-solving activities.
2. Assignments and individual presentations.
3. Student-led classroom teaching.
4. Group discussions.

Assessment Framework

Modes	Written	Oral	Integrated
Formative (50 Marks)	Class Test, Open Book Test, Quiz, Online Test, Class Assignment, Home Assignment	Oral Test, Viva-Voce, Seminar	Presentation, Seminars
Summative (50 marks)	End-Semester Examination conducted by the University		

Note: The course teacher may select an appropriate mode of formative assessment based on the nature of the Course Learning Outcomes (CLOs) and its practicality.

Suggested Readings

- D. S. Watkins, Fundamentals of Matrix Computations, 2nd Ed., John Wiley, 2002.
- L. N. Trefethen and D. Bau, Numerical Linear Algebra, SIAM, 1997.
- G. H. Golub and C. F. Van Loan, Matrix Computations, 3rd Ed., John Hopkins University Press, 1996.

Note**: Latest edition of text books and reference books may be used.**

Name of the Programme: PhD coursework

Course Code: MAT-E-707; Name of the Course: Mathematical and Computational Biology

Course Credits	**No. of Hours per Week**	**Total No. of Teaching Hours**
4 Credits	L/T/P: 2+1+2 hrs	60 Hrs

Course Learning Outcomes (CLOs)	After completion of the course students will be: 1. Able to handle more advanced problems in computational biology. 2. Able to deal with biological data. 3. Understand the basic results. 4. Able to apply it to solve problems in other fields.

Unit	**Unit Title**	**Contents**
I	Statistical data analysis and modelling	Statistical modelling; Data fitting to models; machine learning techniques: supervised and unsupervised classifications, regressions, neural nets.
II	Biological data and bioinformatics	DNA, RNA and protein sequences; algorithms of sequence alignments; phylogenetic tree constructions; protein 3D structure and sequence and structural bioinformatics tools.
III	Systems biology	Biological network; network analysis using graph theory, dynamic network, feedback and feedforward models for biological control systems.
IV	Python, R-programming and MATLAB	Data organization and analysis, graphs and plotting tools, matrices, differential equations and simulations.

Skill Developments Activities: *(These activities are only indicative; the Faculty member can innovate)*

- Problem solving.
- Group discussions.
- Application to other fields.

Suggested-teaching learning strategy

1. Lecture with interactive discussions and problem-solving activities.
2. Assignments and individual presentations.
3. Student-led classroom teaching.
4. Group discussions.

Assessment Framework

Modes	Written	Oral	Integrated
Formative (50 Marks)	Class Test, Open Book Test, Quiz, Online Test, Class Assignment, Home Assignment	Oral Test, Viva-Voce, Seminar	Presentation, Seminars
Summative (50 marks)	End-Semester Examination conducted by the University		

Note: The course teacher may select an appropriate mode of formative assessment based on the nature of the Course Learning Outcomes (CLOs) and its practicality.

Suggested Readings

- Little, J.B. (2019) Modeling and Data Analysis. American Mathematical Society.
- Murray, J.D. (1990) Mathematical Biology. Springer.
- He,M., Petoukhov, S. (2011) Mathematics of bioinformatics: theory, practice and applications John Wiley & Sons Inc.
- Zhang, Y.Q., Jagath C. Rajapakse, J.C. (2008) Machine learning in bioinformatics. John Wiley & Sons Inc.
- Mark, S. (2009). Programming in Python. Pearson Education India.

Note**: Latest edition of text books and reference books may be used.**

Name of the Programme: PhD coursework **Course Code: MAT-E-708; Name of the Course: Graphs and Matrices**			
Course Credits		**No. of Hours per Week**	**Total No. of Teaching Hours**
4 Credits		L/T/P: 3+1+0 hrs	60 Hrs
Course Learning Outcomes (CLOs)		After completion of the course students will be: 1. Able to handle more advanced problems. 2. Able to deal with different forms of graphs and matrices. 3. Understand the basic results. 4. Able to apply it to solve problems in other fields.	
Unit	**Unit Title**	**Contents**	
I	Incidence and Adjacency matrix	Eigenvalues of symmetric matrices, Smith Normal form of a matrix and its applications, Perron– Frobenius theory, Graphs, Incidence Matrix, Path matrix, Matchings in bipartite graphs, Adjacency Matrix, Eigenvalues of some graphs.	
II	Laplacian matrix	Laplacian Matrix, Basic properties, Computing Laplacian eigenvalues, Matrix-tree theorem, Bounds for Laplacian spectral radius, Edge–Laplacian of a tree, Cycles and Cuts, Fundamental cycles and fundamental cuts.	
III	Regular Graphs and Algebraic Connectivity	Adjacency algebra of a regular graph, Complement and line graph of a regular graph, strongly regular graphs and friendship theorem, Graphs with maximum energy, Classification of trees, Monotonicity properties of Fiedler vector, Bounds for algebraic connectivity.	
IV	Positive Definite Completion Problem	Distance Matrix of a Tree, Distance matrix of a graph, Distance matrix and Laplacian of a tree, Eigenvalues of the distance matrix of a tree, Network flows, A random walk on graphs, Effective resistance in electrical networks. Positive Definite Completion Problem, Non-singular completion, Positive definite completion.	

Skill Developments Activities: *(These activities are only indicative; the Faculty member can innovate)*

- Problem solving.
- Group discussions.
- Application to other fields.

Suggested-teaching learning strategy
1. Lecture with interactive discussions and problem-solving activities.
2. Assignments and individual presentations.
3. Student-led classroom teaching.
4. Group discussions.

Assessment Framework

Modes	**Written**	**Oral**	**Integrated**
Formative (50 Marks)	Class Test, Open Book Test, Quiz, Online Test, Class Assignment, Home Assignment	Oral Test, Viva-Voce, Seminar	Presentation, Seminars
Summative (50 marks)	End-Semester Examination conducted by the University		

Note: The course teacher may select an appropriate mode of formative assessment based on the nature of the Course Learning Outcomes (CLOs) and its practicality.

Suggested Readings

- Bapat, R.B. (2010) Graphs and Matrices, Texts and Readings in Mathematics, Hindustan Book Agency, New Delhi
- D. M. Cvetkovic, D.M., Doob, M, Sachs, H. (1980) Spectra of Graphs: Theory and Applications, Academic Press.
- Godsil, C., Royale, G. (2001) Algebraic Graph Theory, Graduate Texts in Mathematics 207, Springer
- Biggs, N. (1974) Algebraic Graph Theory. Cambridge University Press.

Note**: Latest edition of text books and reference books may be used.**

Name of the Programme: PhD coursework
Course Code: MAT-E-709; Name of the Course: Homological Algebra

Course Credits	**No. of Hours per Week**	**Total No. of Teaching Hours**
4 Credits	L/T/P: 3+1+0 hrs	60 Hrs

Course Learning Outcomes (CLOs)

After completion of the course students will be:
1. Able to solve various problems.
2. Understand the basic results.
3. Able to apply it to solve problems in other fields.

Unit	**Unit Title**	**Contents**
I	Categories and functors	Review of Rings and Modules, Categories and functors**,** Additive and abelian categories,
II	Homology	Satellites, Exact sequences, Projective and injective objects, Homology
III	Derived functors	Derived functors, Applications: Tor and Ext; Group cohomology; Sheaf cohomology

IV	Spectral sequences	Spectral sequences, Applications of Spectral Sequences, The derived category

Skill Developments Activities: *(These activities are only indicative; the Faculty member can innovate)*

- Problem solving.
- Group discussions.
- Application to other fields.
-

Suggested-teaching learning strategy

1. Lecture with interactive discussions and problem-solving activities.
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Assessment Framework

Modes	**Written**	**Oral**	**Integrated**
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Summative (50 marks)	End-Semester Examination conducted by the University		

Note: The course teacher may select an appropriate mode of formative assessment based on the nature of the Course Learning Outcomes (CLOs) and its practicality.

Suggested Readings

- Homological Algebra - by H. Cartan, S. Eilenberg.
- An introduction to homological algebra. C. A. Weibel.
- A user's guide to spectral sequences. J. Mc Cleary.
- An introduction to homological algebra. J. J. Rotman.

Note**: Latest edition of text books and reference books may be used.**