OLLSCOIL TEICNEOLAÍOCHTA BHAILE ÁTHA CLIATH
DUBLIN
TECHNOLOGICAL UNIVERSITY DUBLIN

APPROVED

MATH 4851: Financial Mathematics 1

Module Details

Module Code:	MATH 4851
Module Long Title:	Financial Mathematics 1 APPROVED
Banner Title:	Financial Mathematics 1
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Sept 2018 (September 2018)
ECTS Credits::	7.5
ISCED Code:	0541 - Mathematics
Current Coordinator::	STEPHEN O SULLIVAN
Module Coordinators:	• SUSAN LAZARUS (19 January 2022 to 20 January 2022) • STEPHEN O SULLIVAN (20 January 2022 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	This module introduces the learner to the mathematics of pricing, construction and hedging of derivative securities. Discrete-time models form the foundation of our treatment with concepts such as change-of-measure and martingales introduced within this framework. Option pricing will be considered from the perspectives of replication and risk-neutral expectation. Parity relationships and binomial pricing methods will be explored for European and American options. Multi-step binomial models will be considered for standard and exotic options. A discrete treatment of Monte-Carlo methods to path-independent and path-dependent options will be considered.
	Expected value versus arbitrage pricing Expected value versus arbitrage pricing, time value of money **Binomial trees** Binomial model, derivative synthesis, replication, Arrow-Debreu securities, risk-neutral measure

Indicative Syllabus	**Martingales, change-of-measure, representation** Stochastic processes, filtrations, claims, conditional expectation, martingales, binomial representation theorem **Binomial option pricing** Vanilla and exotic option pricing on multi-step binomial lattices, pricing inequalities **Discrete time Monte-Carlo pricing** Martingale measure pricing, confidence intervals for option prices

Learning and Teaching Methods	Lectures supported by problem-solving sessions and the use of mathematical software packages where applicable

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	develop effective and efficient self-directed study skills
MLO2	self-evaluate learning needs and manage learning tasks independently
MLO3	reflect on unfamiliar concepts and successfully contextualize within personal experience – in particular, concepts including rational markets, arbitrage-free option pricing, and risk-neutral probability measures
MLO4	demonstrate the application of various concepts of hedging and pricing by arbitrage in a discrete time framework to problems
MLO5	price vanilla and exotic options within multi-step recombinant binomial models
MLO6	apply Monte-Carlo techniques with confidence interval analysis to discrete-time path-dependent and path-independent option pricing models

Requisites

Module Content & Assessment

Assessment Breakdown	**%**
Formal Examination	75.00%
Other Assessment(s)	25.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	75
Indicative Week	Week 14	**Learning Outcomes**	1,2,3,4,5,6
Assessment Threshold:	35	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Other Assessment(s)

Assessment Type	Practical Assignment	**% of Total Mark for Module**	25
Indicative Week	Week 8	**Learning Outcomes**	1,2,3,4,5,6
Assessment Threshold:	None	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
Assignment

Module Activity

Part Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	111
Hours (up to 100 for 5 ECTS credits)	150.00

Recommended Reading List

Recommended Book Resources

JOHN. HULL. (2021), Options, Futures, and Other Derivatives, Global Edition, Pearson, [ISBN: 1292410655].

Supplementary Book Resources

Ali Hirsa,Salih N. Neftci. An Introduction to the Mathematics of Financial Derivatives, [ISBN: 012384682X].

Fima C Klebaner. (2005), Introduction To Stochastic Calculus With Applications (2nd Edition), World Scientific Publishing Company, p.432, [ISBN: 9781848168220].

Steven Shreve. (2005), Stochastic Calculus for Finance I, Springer Science & Business Media, p.187, [ISBN: 978-0387249681].

Steven E. Shreve. (2004), Stochastic Calculus for Finance II, Springer Science & Business Media, p.550, [ISBN: 978-0387401010].

Paul Wilmott,Susan Howson,Sam Howison,Wilmott-Howison-Dewynne ...,Jeff Dewynne. (1995), The Mathematics of Financial Derivatives, Cambridge University Press, p.317, [ISBN: 978-0521497893].

APPROVED

MATH 4855: Fluid Mechanics 1

Module Details

Module Code:	MATH 4855
Module Long Title:	Fluid Mechanics 1 APPROVED
Banner Title:	Fluid Mechanics 1
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Sept 2023 (September 2023)
Language of Instruction:	English
ECTS Credits::	7.5
ISCED Code:	0541 - Mathematics
Current Coordinator::	ROSSEN IVANOV
Module Coordinators:	ROSSEN IVANOV (10 February 2023 to ---)
School Responsible:	School of Mathematics & Statistics
Campus:	City Campus
Module Overview	This module presents the fundamental and more advanced principles of fluid mechanics and illustrates them by application to a variety of problems of scientific interest. The fundamental aspects of classical fluid mechanics will be investigated and techniques will be provided for solving specific classes of fluid problems. Preliminary concepts such pressure, mass, momentum, energy, inviscid fluids and dimensional reasoning will be introduced. Stresses and strains on a fluid element will be analysed. Bernoulli's equation and Euler's equation will be introduced. Flow kinematics, such as the acceleration of a fluid particle and flow lines will be analysed and accompanied with examples. The equation of conservation of mass will be derived. Complex variable techniques will be used to solve fluid flow problems. Water waves, including surface gravity waves, sinusoidal waves on deep water, and particle paths for travelling waves will be presented.
Learning and Teaching Methods	Lectures are primarily used to impart module content to the learner. Problem solving sessions and tutorials to support learners and are designed to encourage learners to work both individually and in groups.

Indicative Syllabus
1. Preliminaries 1.1) Properties of fluids, the continuum model, pressure, mass, momentum, density, viscosity, energy, inviscid fluids, stream functions, velocity potentials, compressibility and incompressibility, irrotationalflows, dimensional reasoning.
2. Flow Kinematics 2.1) Lagrangian and Eulerian descriptions, material derivative, acceleration of a fluid particle, streamlines, pathlines, streaklines, vorticity.
3. Fundamental Equations 3.1) Conservation of mass equation, the continuity equation, Bernoulli's equation, momentum and energyequations. Euler's equations and the Navier-Stokes equations.

4. Ideal Fluid Flow 4.1) Complex variable techniques, complex potential and complex velocity, aerofoil theory.
5. Water Waves 5.1) Surface gravity waves, sinusoidal waves on deep water, particle paths for travelling waves on deep water.

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	Describe and explain the phenomena which are associated with the various properties of fluids.
MLO2	Analyse flow kinematics of a fluid.
MLO3	Compute streamlines, pathlines and streaklines for particular flows.
MLO4	Derive the continuity equation. Interpret stream functions and velocity potentials.
MLO5	Analyse ideal fluid flow and use complex variable techniques to solve fluid flow problems.
MLO6	Formulate the equations governing the motion of surface gravity waves and find particle paths for travelling waves.

Requisites

Module Content & Assessment

Assessment Breakdown	%
Formal Examination	75.00%
Other Assessment(s)	25.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	75
Indicative Week	Week 14	**Learning Outcomes**	1,2,3,4,5,6
Assessment Threshold:	35	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
End of module examination.

Other Assessment(s)

Assessment Type	Problem-Based Assignment	**% of Total Mark for Module**	25
Indicative Week	See Student Handbook	**Learning Outcomes**	1,2,3,4
Assessment Threshold:	None	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
Continuous assessment during the semester.

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	111
Hours (up to 100 for 5 ECTS credits)	150.00

Part Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	111
Hours (up to 100 for 5 ECTS credits)	150.00

Recommended Reading List

Recommended Book Resources

I.G. Currie. (2012), Fundamental Mechanics of Fluids, Fourth Edition, CRC Press, p.607, [ISBN: 9781439874608].

Frank M. White. (2021), Fluid Mechanics, 9th edition. McGraw Hill, [ISBN: 9781260258318].

Supplementary Book Resources

Yunus A. Çengel, John M. Cimbala. (2019), Fluid Mechanics: Fundamentals and Applications, 4th edition. 15 chapters, McGraw Hill, [ISBN: 9789813157880].

D. J. Acheson. (1990), Elementary Fluid Dynamics, Oxford University Press, p.408, [ISBN: 9780198596790].

Hermann Schlichting, Klaus Gersten. (2016), Boundary-Layer Theory, 9-th edition. Springer, p.782, [ISBN: 9783662529171].

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MATH 4845: Group Theory

Module Details

Module Code:	MATH 4845
Module Long Title:	Group Theory APPROVED
Banner Title:	Group Theory
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Sept 2020 (September 2020)
Language of Instruction:	English

ECTS Credits::	7.5

ISCED Code:	0541 - Mathematics

Current Coordinator::	SUSAN LAZARUS

Module Coordinators:	SUSAN LAZARUS (24 November 2021 to ---)

School Responsible:	School of Mathematical Sciences (CC)

Campus:	City Campus

Module Overview	The module begins with a review of important properties of the integers. It continues to investigate the algebraic systems of groups.

Indicative Syllabus	**Preliminaries** : Integers, Equivalence Relations, Congruences. **Group Theory** Historical development of groups and groups of transformations. Examples of groups, Dihedral groups, Symmetric groups, cyclic groups. Order of groups and the order of elements in a group.

	Group homomorphisms and isomorphisms. Cayley's theorem and left regular representation of a group. Cosets and Lagrange's theorem. Normal subgroups, Quotient groups and the Homomorphism Theorems. Direct product of Groups. Group actions on a set.

Learning and Teaching Methods	Lectures supported by tutorials

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	develop effective and efficient self-directed study skills
MLO2	self-evaluate learning needs and manage learning tasks independently
MLO3	explain the group axioms and identify whether or not a given system is a group
MLO4	describe and explain the many examples of groups discussed in class
MLO5	identify whether or not given subsets are subgroups of a given group
MLO6	explain the concept of the order of a group and the order of a group element
MLO7	identify cyclic subgroups and cyclic groups
MLO8	identify whether or not a subgroup is a normal subgroup of a given group
MLO9	explain the concept of cosets of a subgroup
MLO10	prove consequences of Lagrange’s Theorem
MLO11	determine if mappings between groups are homomorphisms and/or isomorphisms and determine the kernel of a homomorphism
MLO12	construct factor groups
MLO13	describe the relationship between normal subgroups, homomorphisms and factor groups

Requisites

Assessment Threshold	There is a threshold of 35% on the written final examination

Module Content & Assessment

Assessment Breakdown	**%**
Formal Examination	75.00%
Other Assessment(s)	25.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	75
Indicative Week	Week 14	**Learning Outcomes**	1,2,3,4,5,6,7,8,9,10,11,12,13
Assessment Threshold:	35	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Other Assessment(s)

Assessment Type	In Class Test	**% of Total Mark for Module**	10
Indicative Week	Week 7	**Learning Outcomes**	1,2,3,4,5,6,7
Assessment Threshold:	None	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Assessment Type	Problem-Based Assignment	**% of Total Mark for Module**	15
Indicative Week	Week 10	**Learning Outcomes**	1,2,8,9,10,11
Assessment Threshold:	None	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Module Activity

Part Time hours per semester	
Activity Type	*Duration (Hours)*
Self Directed	111
Lecture	39
Hours (up to 100 for 5 ECTS credits)	150.00

Recommended Reading List

Recommended Book Resources

Joseph Gallian. (2016), Contemporary Abstract Algebra, Cengage Learning, p.656, [ISBN: 1305657969].

I. N. Herstein. (1996), Abstract Algebra, Wiley, p.272, [ISBN: 0471368792].

John B. Fraleigh. A First Course in Abstract Algebra, [ISBN: 1292024968].

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MATH 4853: Introduction to Partial Differential Equations

Module Details

Module Code:	MATH 4853
Module Long Title:	Introduction to Partial Differential Equations APPROVED
Banner Title:	Intro to Partial Differential Equations
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Sept 2020 (September 2020)
Language of Instruction:	English
ECTS Credits::	7.5
ISCED Code:	0541 - Mathematics
Current Coordinator::	COLUM WATT
Module Coordinators:	COLUM WATT (22 October 2019 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	Partial differential equations occur throughout mathematical modelling from meteorology and continuum mechanics, to financial mathematics, quantum mechanics, mathematical biology and electromagnetism. This module presents some of the theory of partial differential equations and some of the methods for solving them. The learner will be able to derive solutions for practical partial differential equations and will develop an understanding of their behaviour.
Indicative Syllabus	Introduction to the definitions and terminology associated with partial differential equations: order, linearity, initial and boundary conditions, Dirichlet & Neumann data. Illustration of these concepts in examples. First-order linear and quasi-linear PDEs, first integrals, theory behind the method of characteristics, the use of the method of characteristics to solve explicit problems, singularities and consistency. Derivation and solution of simple first order models (for example, a simple traffic flow model). The method of separation of variables for linear first order PDEs, the use of this method to solve explicit problems. Non-linear PDEs, derivation of the Lagrange-Charpit equations and some consequences, use of the Lagrange-Charpit equations to solve explicit problems.

	The classification of linear second order PDEs, examples, the definition and calculation of characteristic curves for linear second order PDEs

Learning and Teaching Methods	Lectures and tutorials.

Indicative Syllabus
1. Basics 1.1) Introduction to the definitions and terminology associated with partial differential equations: order, linearity, initial and boundary conditions, Dirichlet & Neumann data. Illustration of these concepts in examples.
2. Method of Characteristics 2.1) First-order linear and quasi-linear PDEs, first integrals, theory behind the method of characteristics, the use of the method of characteristics to solve explicit problems, singularities and consistency.
3. Simple Models 3.1) Derivation and solution of simple first order models (for example, a simple traffic flow model).
4. Separation of Variables 4.1) The method of separation of variables for linear first order PDEs, the use of this method to solve explicit problems.
5. 1st order Nonlinear PDEs 5.1) Non-linear PDEs, derivation of the Lagrange-Charpit equations and some consequences, use of the Lagrange-Charpit equations to solve explicit problems.
6. Linear 2nd Order PDEs 6.1) The classification of linear second order PDEs, examples, the definition and calculation of characteristic curves for linear second order PDEs

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	Apply effective and efficient self-directed study skills in their learning process.
MLO2	Apply the method of characteristics to determine first integrals and to solve first-order, quasi-linear, PDEs.
MLO3	Transform first-order, quasi-linear PDEs to their canonical form.
MLO4	Apply separation of variables to solve first-order, linear PDEs.
MLO5	Derive the Lagrange-Charpit equations and some of their consequences.
MLO6	Apply the Lagrange-Charpit equations to solve first-order, nonlinear PDEs.
MLO7	Derive simple models such as that for traffic flow.
MLO8	Classify second order, linear PDEs as elliptic, parabolic or hyperbolic and calculate the corresponding characteristic curves.
MLO9	Explain the limitations of the methods of solution encountered in this module.

Requisites

Assessment Threshold	There is a threshold of 35% on the formal examination.

Module Content & Assessment

Assessment Breakdown	**%**
Formal Examination	75.00%
Other Assessment(s)	25.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	75
Indicative Week	Week 19	**Learning Outcomes**	1,2,3,4,5,6,7,8,9
Assessment Threshold:	35	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Other Assessment(s)

Assessment Type	Problem-Based Assignment	**% of Total Mark for Module**	25
Indicative Week	Week 10	**Learning Outcomes**	1,2,3,4,6
Assessment Threshold:	None	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
The mid-semester assessment will consist of several problems whose solution is required.

Module Activity

Part Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	111
Hours (up to 100 for 5 ECTS credits)	150.00

Recommended Reading List

Recommended Book Resources

L. Debnath and Tyn Myint-U. (2010), Linear Partial Differential Equations, Birkhauser.

L. Debnath. (2011), Nonlinear Partial Differential Equations for Scientists and Engineers, 3rd. Birkhauser.

D.W. Thoe and E.C. Zachmanoglou. (1987), Introduction to Partial Differential Equations with Applications, Dover.

Supplementary Book Resources

J. David Logan. (2008), Introduction to Nonlinear Partial Differential Equations, 2nd. Wiley.

J. Ockendon, S. Howison, A. Lacey. & A. Movchan. (2003), Applied Partial Differential Equations, Oxford University Press.

I.M. Sneddon. (2006), Elements of Partial Differential Equations, Dover.

W.E. Williams. (1980), Partial Differential Equations, Oxford Clarendon Press.

J. Blackledge, G. Evans, P. Yardley. (1999), Analytic Methods for Partial Differential Equations, Springer.

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HEAD OF SCHOOL

MATH 4849: Quantum Theory 1

Module Details

Module Code:	MATH 4849
Module Long Title:	Quantum Theory 1 HEAD OF SCHOOL
Version:	1
Valid From:	Sept 2018 (September 2018)
Language of Instruction:	English
ECTS Credits::	7.5
Current Coordinator::	EMIL MIHAYLOV PRODANOV
Module Coordinators:	EMIL MIHAYLOV PRODANOV (14 January 2022 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	This module introduces the students to quantum mechanics from first principles. Simple quantum systems will be studied and the formalism of quantum theory introduced both in terms of wave functions (Schrödinger formulation) and matrices (Heisenberg’s formulation).
Learning and Teaching Methods	Lectures supported by tutorials

Indicative Syllabus
1. The Wave Function 1.1) The Schrödinger equation. Statistical interpretation. Probability. Normalization. 1.2) Momentum. The Uncertainty Principle
2. Time-independent Schrödinger Equation 2.1) Stationary states. The infinite square well. The harmonic oscillator. The free particle. 2.2) The Dirac delta-function. The delta-function potential. The S-matrix.
3. Formalism 3.1) Hilbert spaces. Observables. Eigenfunctions of a Hermitian operator. Generalized statistical interpretation. The Uncertainty Principle. Dirac notation.
4. Quantum Mechanics in three dimensions 4.1) The Schrödinger equation in spherical coordinates. The Hydrogen atom. Angular Momentum. Spin

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	Apply effective and efficient self-directed study skills in their learning process
MLO2	Self-evaluate learning needs and manage learning tasks independently
MLO3	Explain the Schrödinger wave function
MLO4	Solve simple one-dimensional quantum mechanical systems
MLO5	Explain the principles and formalism of quantum theory
MLO6	Solve Schrödinger's equation for the Hydrogen atom and interpret the solution

Requisites

Module Content & Assessment

Assessment Breakdown	**%**
Formal Examination	75.00%
Other Assessment(s)	25.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	75
Indicative Week	Week 1	**Learning Outcomes**	1,2,3,4,5,6
Assessment Threshold:	None	**Assessment Role**	Not yet determined
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
End-of-module Final Exam

Other Assessment(s)

Assessment Type	In Class Test	**% of Total Mark for Module**	25
Indicative Week	Week 1	**Learning Outcomes**	1,2,3,4
Assessment Threshold:	None	**Assessment Role**	Not yet determined
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Self Directed	111
Hours (up to 100 for 5 ECTS credits)	111.00

Recommended Reading List

Recommended Book Resources

David J. Griffiths, Darrell F. Schroeter. (2018), Introduction to Quantum Mechanics, Cambridge University Press, p.500, [ISBN: 978-1107189638].

Supplementary Book Resources

Albert Messiah. (2014), Quantum Mechanics, Courier Corporation, p.1152, [ISBN: 978-0486784557].

L D Landau, E.M. Lifshitz. (1991), Quantum Mechanics, Butterworth-Heinemann, p.677, [ISBN: 978-0750635394].

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APPROVED

MATH 4848: Queuing Theory & Stochastic Processes

Module Details

Module Code:	MATH 4848
Module Long Title:	Queuing Theory & Stochastic Processes APPROVED
Banner Title:	Queuing Theory & Stochastic Processes
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Jan 2019 (January 2019)
Language of Instruction:	English
ECTS Credits::	7.5
ISCED Code:	0541 - Mathematics
Current Coordinator::	MAEV P MAGUIRE
Module Coordinators:	MAEV P MAGUIRE (07 January 2022 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	This module introduces the learner to the concept of single and multiple server models, infinite and finite, and variable arrival and service rates. It introduces stochastic processes, and Markov chains and its applications. Case studies of both areas are covered and solved using appropriate software.

Queuing Theory

Introduction to queuing models. Poisson arrival pattern. Negative exponential service pattern.

Different queuing models - *M/M/* 1 and *M/M/* S infinite models, *M/M/* 1 and *M/M/* S finite models.

M/M/ 1 with varying arrival patterns and service rates.

Derivation and analysis of mean queuing times, mean number of customers in the system, etc. for above models.

Applications to queueing problems and case studies.

Indicative Syllabus	**Stochastic Processes** Review of matrix analysis. Definition of primitive/imprimitive matrices, reducible/irreducible matrices. Definition of a stochastic process and Markov chains. First-order and higher order transition matrices. Classifications of states of a Markov chain - absorbing, persistent, transient, periodic, null, non-null, ergodic. Theorems relating states, long-term probabilities, etc. Existence of limits for irreducible ergodic chains. Applications and case studies.

Learning and Teaching Methods	Lectures and supporting tutorials and laboratory sessions Use of software packages to solve problems.

Indicative Syllabus
1. Queuing Theory 1.1) Introduction to queuing models. Poisson arrival pattern. Negative exponential service pattern. 1.2) Different queuing models - M/M/1 and M/M/S infinite models, M/M/1 and M/M/S finite models. 1.3) M/M/1 with varying arrival patterns and service rates. 1.4) Derivation and analysis of mean queuing times, mean number of customers in the system, etc. for above models. 1.5) Applications to queueing problems and case studies.
2. Stochastic Processes 2.1) Review of matrix analysis. 2.2) Definition of primitive/imprimitive matrices, reducible/irreducible matrices. 2.3) Definition of a stochastic process and Markov chains. 2.4) First-order and higher order transition matrices. 2.5) Classifications of states of a Markov chain - absorbing, persistent, transient, periodic, null, non-null, ergodic. Theorems relating states, long-term probabilities, etc. Existence of limits for irreducible ergodic chains. 2.6) Applications and case studies.

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	develop effective and efficient self-directed study skills
MLO2	self-evaluate learning needs and manage learning tasks independently
MLO3	Identify queueing models
MLO4	Demonstrate an understanding of the arrival and service process
MLO5	Describe particular queueing models using various methods
MLO6	Derive the quantities of interest for particular queueing models
MLO7	Solve real life queueing problems
MLO8	Define primitive and irreducible matrices
MLO9	Define stochastic processes and Markov Chains
MLO10	Compute first and higher order transition probabilities
MLO11	Classify the states of a Markov Chain
MLO12	Recognise irreducible ergodic chains with proofs

Requisites

Assessment Threshold	35% on Exam Component

Module Content & Assessment

Assessment Breakdown	**%**
Formal Examination	75.00%
Other Assessment(s)	25.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	75
Indicative Week	Week 14	**Learning Outcomes**	1,2,3,4,5,6,7,8,9,10,11,12
Assessment Threshold:	35	**Assessment Role**	Not yet determined
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
End of semester Examination

Other Assessment(s)

Assessment Type	In Class Test	**% of Total Mark for Module**	25
Indicative Week	Week 7	**Learning Outcomes**	1,2,3,4,5,6
Assessment Threshold:	None	**Assessment Role**	Not yet determined
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
In class test or other appropriate assessment

Module Activity

Part Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	111
Hours (up to 100 for 5 ECTS credits)	150.00

Recommended Reading List

Recommended Book Resources

Hamdy A. Taha. (2007), Operations Research, Prentice Hall, p.813, [ISBN: 9780131889231].

Jyotiprasad Medhi. (2010), Stochastic Processes, New Academic Science, p.503, [ISBN: 9781906574307].

Supplementary Book Resources

David Ray Anderson,Dennis J. Sweeney,Thomas Arthur Williams,Mik Wisniewski. An Introduction to Management Science, [ISBN: 9781408088401].

APPROVED

MATH 4852: Financial Mathematics 2

Module Details

Module Code:	MATH 4852
Module Long Title:	Financial Mathematics 2 APPROVED
Banner Title:	Financial Mathematics 2
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Jan 2019 (January 2019)
ECTS Credits::	7.5
ISCED Code:	0541 - Mathematics
Current Coordinator::	STEPHEN O SULLIVAN
Module Coordinators:	• SUSAN LAZARUS (17 November 2021 to 19 January 2022) • STEPHEN O SULLIVAN (19 January 2022 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	This module introduces the learner to the mathematics of hedging and pricing of financial derivatives by arbitrage in a continuous-time framework by building on prior knowledge of discrete-time models. Key concepts such as conditional expectation, martingales, change-of-measure, Wiener processes, and Ito calculus are developed in the lead up to the derivation of the Black-Scholes formula and Black-Scholes equation. Monte Carlo methods are considered for solving stochastic differential equations
	Brownian motion Transition from discrete to continuous processes, properties of Brownian motions **Stochastic calculus** Non-stochastic calculus, stochastic integration and differentials, Ito's Lemma, Ito calculus

Indicative Syllabus	**Change of measure** Girsanov's theorem, martingale representation theorem **Black Scholes formula and equation** Derivation, pricing, manipulation **Monte-Carlo methods for option pricing** Euler scheme, Milstein scheme, convergence

Learning and Teaching Methods	Lectures supported by problem-solving sessions and the use of mathematical software packages where applicable.

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	develop effective and efficient self-directed study skills
MLO2	self-evaluate learning needs and manage learning tasks independently
MLO3	reflect on unfamiliar concepts and successfully contextualize within personal experience – in particular, concepts including rational markets, arbitrage-free option pricing, and risk-neutral probability measures
MLO4	characterize and identify Wiener processes
MLO5	establish and apply Ito’s lemma
MLO6	treat expectations under change-of-measure
MLO7	derive and manipulate the Black-Scholes formula and Black-Scholes equation
MLO8	demonstrate Monte-Carlo numerical methods for option pricing

Requisites		
Requisite Type	***Module Title***	***Type***
Pre Requisite	MATH 4851 v.1 Financial Mathematics 1 [Approved]	Module

Assessment Threshold	35% on final written examination

Module Content & Assessment

Assessment Breakdown	%
Formal Examination	75.00%
Other Assessment(s)	25.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	75
Indicative Week	Week 14	**Learning Outcomes**	1,2,3,4,5,6,7,8
Assessment Threshold:	35	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Other Assessment(s)

Assessment Type	Practical Assignment	**% of Total Mark for Module**	25
Indicative Week	Week 8	**Learning Outcomes**	1,2,3,4,5,6,7,8
Assessment Threshold:	None	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
Assignment

Module Activity

Part Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	111
Hours (up to 100 for 5 ECTS credits)	150.00

Recommended Reading List

Recommended Book Resources

JOHN. HULL. (2021), Options, Futures, and Other Derivatives, Global Edition, Pearson, [ISBN: 978-1292410654].

Supplementary Book Resources

Paul Wilmott,Susan Howson,Sam Howison,Wilmott-Howison-Dewynne ...,Jeff Dewynne. (1995), The Mathematics of Financial Derivatives, Cambridge University Press, p.317, [ISBN: 978-0521497893].

Steven E. Shreve. (2004), Stochastic Calculus for Finance II, Springer Science & Business Media, p.550, [ISBN: 978-0387401010].

Steven Shreve. (2005), Stochastic Calculus for Finance I, Springer Science & Business Media, p.187, [ISBN: 978-0387249681].

Fima C Klebaner. (2005), Introduction To Stochastic Calculus With Applications (2nd Edition), World Scientific Publishing Company, p.432, [ISBN: 9781848168220].

Salih N. Neftci,Ali Hirsa,Salih N.. Neftci. (2000), An Introduction to the Mathematics of Financial Derivatives, Academic Press, p.527, [ISBN: 978-0125153928].

APPROVED

MATH 4856: Fluid Mechanics 2

Module Details

Module Code:	MATH 4856
Module Long Title:	Fluid Mechanics 2 APPROVED
Banner Title:	Fluid Mechanics 2
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Sept 2023 (September 2023)
Language of Instruction:	English
ECTS Credits::	7.5
ISCED Code:	0541 - Mathematics
Current Coordinator::	ROSSEN IVANOV
Module Coordinators:	ROSSEN IVANOV (10 February 2023 to ---)
School Responsible:	School of Mathematics & Statistics
Campus:	City Campus
Module Overview	This module builds on the material covered in the Fluid Mechanics 1 module. The conservation of momentum equation is used to derive the Navier-Stokes equations. Non dimensional quantities such as the Reynold's number are explored. Derivation of the Navier-Stokes equations and some simple solutions of them, such as pipe flow and flow down an inclined plane will be presented. Slow viscous flows and the biharmonic equation will be analysed. The boundary layer equations will be derived and solved for some simple flows. The approximate Pohlhausen method will be used to solve the boundary layer equations. The fundamental processes governing oceanic and dry atmospheric motions will be investigated. Accelerations relative to the Earth's rotating frame, Coriolis and centrifugal forces, and small amplitude motion in a fluid rotating at constant velocity will be presented. Geostrophic adjustment, geostrophic balance and thermal wind, Ekman layers and barotropic Rossby waves will be analysed.
Learning and Teaching Methods	Lectures are primarily used to impart module content to the learner. Problem solving sessions and tutorials to support learners and are designed to encourage learners to work both individually and in groups.

Indicative Syllabus
1. Derivation and Solutions of the Navier-Stokes equations 1.1) Rate of strain matrix and its diagonalisation, principal axes and principal rates of strain. Rates of translation, rotation, linear strain and shear strain. Newtonian fluids, derivation and solutions of the Navier-Stokes equations, to include Couette flow, flow in a pipe, flow down an inclined plane. Non-dimensionalisation of the Navier- Stokes equations. Orders of magnitude. The Reynolds number.
2. Slow Viscous Flows 2.1) Stokes flows, derivation of the biharmonic equation and some solutions of it.
3. Boundary Layer Theory 3.1) Derivation of the boundary layer equations and some solutions of them. The Blasius solution. The approximate Pohlhausen method.

4. Geophysical Fluid Motion
4.1) Accelerations relative to the Earth's rotating reference frame, Coriolis and centrifugal forces, Ekman layers and barotropic Rossby waves.

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	Describe and explain the rate of strain matrix and the fundamental kinematic properties of fluid motion and deformation.
MLO2	Diagonalise the rate of strain matrix in order to calculate principal axes and principal rates of strain.
MLO3	Derive and calculate some exact solutions of the Navier-Stokes equations. Dimensional analysis. Reynolds number.
MLO4	Derive the equations governing the motion of slow viscous flow from the Navier-Stokes equations.
MLO5	Solve the biharmonic equation for some specific flows.
MLO6	Derive the boundary layer equations from the Naiver-Stokes equations.
MLO7	Apply and interpret the Pohlhausen method to find simple solutions of the boundary layer equations.
MLO8	Explain aspects of geophysical fluid motion, such as the fundamental processes governing oceanic and dry atmospheric motions.

Requisites		
Requisite Type	***Module Title***	***Type***
Pre Requisite	MATH 4855 v.1 Fluid Mechanics 1 [Approved]	Module

Module Content & Assessment

Assessment Breakdown	**%**
Formal Examination	75.00%
Other Assessment(s)	25.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	75
Indicative Week	Week 30	**Learning Outcomes**	1,2,3,4,5,6,7,8
Assessment Threshold:	None	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
End of module examination

Other Assessment(s)

Assessment Type	Problem-Based Assignment	**% of Total Mark for Module**	25
Indicative Week	See Student Handbook	**Learning Outcomes**	1,2,3,4
Assessment Threshold:	None	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
Continuous assessment during the semester.

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	111
Hours (up to 100 for 5 ECTS credits)	150.00

Part Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	111
Hours (up to 100 for 5 ECTS credits)	150.00

Recommended Reading List

Recommended Book Resources

I.G. Currie. (2012), Fundamental Mechanics of Fluids, Fourth Edition, CRC Press, p.607, [ISBN: 9781439874608].

Joseph Pedlosky. (1992), Geophysical Fluid Dynamics, Springer, p.710, [ISBN: 978-0-387-96387-7].

Supplementary Book Resources

Frank M. White. (2021), Fluid Mechanics, 9th edition. McGraw Hill, [ISBN: 9781260258318].

D. J. Acheson. (1990), Elementary Fluid Dynamics, Oxford University Press, p.408, [ISBN: 9780198596790].

Hermann Schlichting, Klaus Gersten. (2016), Boundary-Layer Theory, 9-th edition. Springer, p.782, [ISBN: 9783662529171].

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APPROVED

MATH 4847: Linear Programming

Module Details

Module Code:	MATH 4847
Module Long Title:	Linear Programming APPROVED
Banner Title:	Linear Programming
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Sept 2019 (September 2019)
Language of Instruction:	English
ECTS Credits::	7.5
ISCED Code:	0541 - Mathematics
Current Coordinator::	MAEV P MAGUIRE
Module Coordinators:	MAEV P MAGUIRE (26 September 2019 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	This module introduces the reader to the subject Operations Research and the topic Linear Programming. It introduces the Simplex method for solving LP problems and artificial variables for finding initial basic feasible solutions. The Fundamental Theorem of Linear Programming and the theory behind the Simplex method are presented. Duality and Sensitivity Analysis are also covered. Case studies will be presented and solved using appropriate software.
Indicative Syllabus	Introduction to and examples of linear programs. Linear programs in standard form. Definitions of feasible, basic feasible and optimal solutions. The fundamental theorem of linear programming (with proof). Relations to convexity. Simplex method - pivots, vectors to leave and enter basis, determining a minimum feasible solution. Artificial variables. Variables with upper bounds. Duality - dual linear programs, the duality theorem.

	Simplex multipliers. sensitivity and complementary slackness. Dual Simplex method. Primal-dual algorithm. Reduction of linear inequalities.

Learning and Teaching Methods	Lectures and supporting tutorials and laboratory sessions

Indicative Syllabus
1. Linear Programming 1.1) Introduction to and examples of linear programs. Linear programs in standard form. 1.2) Definitions of feasible, basic feasible and optimal solutions. 1.3) The fundamental theorem of linear programming (with proof). 1.4) Relations to convexity. 1.5) Simplex method - pivots, vectors to leave and enter basis, determining a minimum feasible solution. 1.6) Artificial variables. Variables with upper bounds. 1.7) Duality - dual linear programs, the duality theorem. 1.8) Simplex multipliers. sensitivity and complementary slackness. 1.9) Dual Simplex method. Primal-dual algorithm. Reduction of linear inequalities.

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	Develop effective and efficient self-directed study skills
MLO2	Self-evaluate learning needs and manage learning tasks independently
MLO3	Recognise problems that can be solved using linear programming
MLO4	Formulate Linear Programming models
MLO5	Prove the Fundamental Theorem of Linear Programming
MLO6	Apply the simplex method to LP problems
MLO7	Use artificial variables to find an initial basic feasible solution
MLO8	Formulate and solve the Dual of LP problems
MLO9	Prove the Duality Theorem
MLO10	Apply sensitivity analysis to LP problems
MLO11	Apply the Dual Simplex method to LP problems

Requisites

Assessment Threshold	35% on exam component

Module Content & Assessment

Assessment Breakdown	%
Formal Examination	75.00%
Other Assessment(s)	25.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	75
Indicative Week	Week 14	**Learning Outcomes**	1,2,3,4,5,6,7,8,9,10,11
Assessment Threshold:	35	**Assessment Role**	Not yet determined
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
End of semester Examination

Other Assessment(s)

Assessment Type	In Class Test	**% of Total Mark for Module**	25
Indicative Week	Week 7	**Learning Outcomes**	1,2,3,4,5,6
Assessment Threshold:	None	**Assessment Role**	Not yet determined
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
In class test or appropriate alternative assessment

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	150
Hours (up to 100 for 5 ECTS credits)	150.00

Recommended Reading List

Recommended Book Resources

David G. Luenberger,Yinyu Ye. (2008), Linear and Nonlinear Programming, Springer Science & Business Media, p.546, [ISBN: 9780387745029].

Hamdy A. Taha. (2007), Operations Research, Prentice Hall, p.813, [ISBN: 978-0131889231].

David Ray Anderson,Dennis J. Sweeney,Thomas Arthur Williams,Mik Wisniewski. An Introduction to Management Science, [ISBN: 9781408088401].

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APPROVED

MATH 4854: Partial Differential Equations and Numerical Methods

Module Details

Module Code:	MATH 4854
Module Long Title:	Partial Differential Equations and Numerical Methods APPROVED
Banner Title:	PDEs and Numerical Methods
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Jan 2021 (January 2021)
Language of Instruction:	English
ECTS Credits::	7.5
ISCED Code:	0541 - Mathematics
Current Coordinator::	COLUM WATT
Module Coordinators:	COLUM WATT (05 January 2022 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	The module presents techniques for solving second and higher order, linear, partial differential equations. Standard analytic methods are used to solve some of the important linear partial differential equations that arise in practical problems. Some numerical methods and their associated theory are also presented and their use illustrated.
Indicative Syllabus	Second and higher order linear PDEs: examples arising from practical problems, boundary conditions; Dirichlet & Neumann data. Derivation of canonical forms of linear, second order PDEs, calculation of canonical forms in explicit examples. Hyperbolic equations: solution by characteristic curves, explicit examples, D'Alembert's solution of the wave equation. Definition and examples of Sturm-Liouville systems; definition and properties of eigenvalues and eigenfunctions of Sturm-Liouville systems; calculation of eigenvalues and eigenfunctions for explicit examples; solution of non-homogeneous systems by orthogonal expansions; examples. Explanation of the method of separation of variables for linear PDEs; the use of this method in solving particular examples of the heat equation, Laplace's equation and the wave equation.

	Finite differences for linear partial differential equations: discussion of the need for, and derivation of, finite difference methods; illustration (by hand) of the use of finite difference methods in small examples; the concepts of convergence, consistency and stability; examples of checking explicit numerical schemes for consistency and stability; the use of Lax's Equivalence Theorem.

Learning and Teaching Methods	Lectures and Tutorials

Indicative Syllabus
1. Basics 1.1) Second and higher order linear PDEs: examples arising from practical problems, boundary conditions; Dirichlet & Neumann data.
2. Canonical Forms 2.1) Derivation of canonical forms of linear, second order PDEs, calculation of canonical forms in explicit examples.
3. D'Alembert's Solution 3.1) Hyperbolic equations: solution by characteristic curves, explicit examples, D'Alembert's solution of the wave equation.
4. Sturm-Liouville Systems 4.1) Definition and examples of Sturm-Liouville systems; definition and properties of eigenvalues and eigenfunctions of Sturm-Liouville systems; calculation of eigenvalues and eigenfunctions for explicit examples; solution of non-homogeneous systems by orthogonal expansions; examples.
5. Separation of Variables 5.1) Explanation of the method of separation of variables for linear PDEs; the use of this method in solving particular examples of the heat equation, Laplace's equation and the wave equation.
6. Finite Difference Methods 6.1) Finite differences for linear partial differential equations: discussion of the need for, and derivation of, finite difference methods; illustration (by hand) of the use of finite difference methods in small examples; the concepts of convergence, consistency and stability; examples of checking explicit numerical schemes for consistency and stability; the use of Lax's Equivalence Theorem.

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	Apply effective and efficient self-directed study skills in their learning process
MLO2	Transform second order linear PDEs to their canonical forms and, hence, solve them in some cases
MLO3	Apply D'Alembert's method to solve the wave equation
MLO4	Calculate the eigenvalues and eigenfunctions of simple Sturm-Liouville systems and use them to solve associated non-homogeneous equations
MLO5	Apply separation of variables to solve standard second order PDEs such as Laplace's equation, the heat equation and the wave equation
MLO6	Derive some of the second order PDEs (such as the wave equation and the heat equation) that arise from physical problems
MLO7	Formulate numerical schemes for solving linear partial differential equations
MLO8	Explore numerical schemes for consistency, stability and convergence

Requisites

Assessment Threshold	There is a threshold of 35% in the formal examination.

Module Content & Assessment

Assessment Breakdown	%
Formal Examination	75.00%
Other Assessment(s)	25.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	75
Indicative Week	Week 18	**Learning Outcomes**	1,2,3,4,5,6,7,8
Assessment Threshold:	35	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Other Assessment(s)

Assessment Type	Problem-Based Assignment	**% of Total Mark for Module**	25
Indicative Week	Week 9	**Learning Outcomes**	1,2,3,4
Assessment Threshold:	None	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Module Activity

Part Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	111
Hours (up to 100 for 5 ECTS credits)	150.00

Recommended Reading List

Recommended Book Resources

L. Debnath and Tyn Myint-U. (2010), Linear Partial Differential Equations, Birkhauser.

J. David Logan. Applied Partial Differential Equations, Springer.

Peter J Olver. (2014), Introduction to Partial Differential Equations, Springer.

Supplementary Book Resources

J. Ockendon, S. Howison, A. Lacey & A. Movchan. (2003), Applied Partial Differential Equations, Oxford University Press.

I.M. Sneddon. (2006), Elements of Partial Differential Equations, Dover.

W.E. Williams. (1980), Partial Differential Equations, Oxford Clarendon Press.

D.W. Thoe and E.C. Zachmanoglou. (1987), Introduction to Partial Differential Equations with Applications, Dover.

J. Blackledge, G. Evans, P. Yardley. (1999), Analytic Methods for Partial Differential Equations, Springer.

HEAD OF SCHOOL

MATH 4850: Quantum Theory 2

Module Details

Module Code:	MATH 4850
Module Long Title:	Quantum Theory 2 HEAD OF SCHOOL
Version:	1
Valid From:	Jan 2019 (January 2019)
ECTS Credits::	7.5
Current Coordinator::	EMIL MIHAYLOV PRODANOV
Module Coordinators:	EMIL MIHAYLOV PRODANOV (14 January 2022 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Module Overview	This module builds on Quantum Theory 1 and presents Quantum Theory from a mathematical perspective.

Indicative Syllabus
1. Angular momentum in quantum mechanics 1.1) n/a
2. Mathematical Apparatus 2.1) The Stern-Gerlach experiment; kets, bras, and operators; base kets and matrix representations; measurements, observables and the uncertainty relations; change of basis; position, momentum, and translation; wave functions in position and momentum space
3. Quantum Dynamics 3.1) Time evolution and the Schrodinger equation; the Schrodinger versus the Heisenberg picture; simple harmonic oscillator; Schrodinger's wave equation

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	Apply effective and efficient self-directed study skills in their learning process
MLO2	Self-evaluate learning needs and manage learning tasks independently
MLO3	Describe the concept of angular momentum in Quantum Mechanics
MLO4	Express the realisation of physical observables as Hermitian operators acting in the space of physical states
MLO5	Explain compatibility and measurement
MLO6	Apply the principles of algebraic approaches to selected quantum mechanical problems
MLO7	Explain how Quantum Mechanics fits in the wider picture of physics and mathematics and the interplay between Quantum Mechanics and other major branches – classical mechanics, linear algebra, group theory, functional analysis
MLO8	Give examples of the mathematical apparatus of Quantum Mechanics
MLO9	Mathematically formulate Quantum Mechanics in both Schrodinger's and Heisenberg's formulations

Requisites		
Requisite Type	***Module Title***	***Type***
Pre Requisite	MATH 4849 v.1 MATH 4849 Quantum Theory 1 [Head of School]	Module

Module Content & Assessment

Assessment Breakdown	%
Formal Examination	75.00%
Other Assessment(s)	25.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	75
Indicative Week	Week 1	**Learning Outcomes**	1,2,3,4,5,6,7,8,9
Assessment Threshold:	None	**Assessment Role**	Not yet determined
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
End-of-module Final Exam

Other Assessment(s)

Assessment Type	In Class Test	**% of Total Mark for Module**	25
Indicative Week	Week 1	**Learning Outcomes**	1,2,3,4,5
Assessment Threshold:	None	**Assessment Role**	Not yet determined
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Self Directed	111
Hours (up to 100 for 5 ECTS credits)	111.00

Recommended Reading List

Recommended Book Resources

J. J. Sakurai, Jim Napolitano. (2020), Modern Quantum Mechanics, Cambridge University Press, p.566, [ISBN: 978-1108473224].

David J. Griffiths, Darrell F. Schroeter. (2018), Introduction to Quantum Mechanics, Cambridge University Press, p.500, [ISBN: 978-1107189638].

Supplementary Book Resources

L D Landau, E.M. Lifshitz. (1991), Quantum Mechanics, Butterworth-Heinemann, p.677, [ISBN: 978-0750635394].

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APPROVED

MATH 4846: Ring Theory with Applications

Module Details

Module Code:	MATH 4846
Module Long Title:	Ring Theory with Applications APPROVED
Banner Title:	Ring Theory with Applications
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Jan 2021 (January 2021)
Language of Instruction:	English
ECTS Credits::	7.5
ISCED Code:	0541 - Mathematics
Current Coordinator::	SUSAN LAZARUS
Module Coordinators:	SUSAN LAZARUS (14 January 2020 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	The module investigates the algebraic systems of rings and looks at some modern applications of ring theory.
Indicative Syllabus	**Ring Theory** Ring axioms and examples of rings and subrings. Commutative rings. Zero-divisors and Integral Domains, division rings and fields. Ring homomorphisms and isomorphisms. Ideals, quotient rings, and the homomorphism theorems. Principal ideal domains, prime ideals, maximal ideals.

	Field of Quotients of a commutativie ring. Divisibility, Euclidean domains, Polynomial rings. Direct sum of rings. **Applications** Construction of finite fields, Random number generators, Error correcting codes.

Learning and Teaching Methods	Lectures supported by tutorials

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	develop effective and efficient self-directed study skills
MLO2	self-evaluate learning needs and manage learning tasks independently
MLO3	explain the different axiomatic structures of rings, integral domains and fields,
MLO4	describe and explain the range of examples of rings, integral domains and fields discussed in class,
MLO5	identify if given subsets are subrings and /or ideals of a given ring,
MLO6	describe different types of ideals (principal, prime, maximal) and identify such ideals,
MLO7	determine if mappings between rings are homomorphisms and/or isomorphisms, and find the kernel of homomorphisms,
MLO8	construct factor rings,
MLO9	explain the relationship between ideals, homomorphisms and factor rings and applications thereof.

Requisites

Assessment Threshold	Threshold of 35% on formal examination

Module Content & Assessment

Assessment Breakdown	**%**
Formal Examination	75.00%
Other Assessment(s)	25.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	75
Indicative Week	Week 14	**Learning Outcomes**	1,2,3,4,5,6,7,8,9
Assessment Threshold:	35	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Other Assessment(s)

Assessment Type	Problem-Based Assignment	**% of Total Mark for Module**	25
Indicative Week	Week 8	**Learning Outcomes**	1,2,3,4,5,6,7
Assessment Threshold:	None	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Module Activity

Part Time hours per semester	
Activity Type	*Duration (Hours)*
Self Directed	111
Lecture	39
Hours (up to 100 for 5 ECTS credits)	150.00

Recommended Reading List

Recommended Book Resources

Joseph Gallian. (2016), Contemporary Abstract Algebra, Cengage Learning, p.656, [ISBN: 1305657969].

I. N. Herstein. (1996), Abstract Algebra, Wiley, p.272, [ISBN: 0471368792].

John B. Fraleigh. A First Course in Abstract Algebra, [ISBN: 1292024968].

APPROVED

MATH 4842: Mathematical Methods II

Module Details

Module Code:	MATH 4842
Module Long Title:	Mathematical Methods II APPROVED
Banner Title:	Mathematical Methods II
Version:	1
Valid From:	Sept 2019 (September 2019)
Language of Instruction:	English
ECTS Credits::	7.5
ISCED Code:	0541 - Mathematics
Current Coordinator::	COLUM WATT
Module Coordinators:	COLUM WATT (07 January 2020 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	This module contains a treatment of advanced mathematical techniques applied to linear ordinary and partial differential equations. The general theory of linear ordinary differential equations is developed and methods of solution, such as the use of series expansions and Green’s functions, are demonstrated. A variety of methods for solving linear partial differential equations are presented and the properties of some of the important functions of mathematical physics are investigated.
Indicative Syllabus	**Linear Ordinary Differential Equations** General theory of linear ordinary differential equations. Power series solutions and the method of Frobenius for second-order, linear, ordinary differential equations. The Dirac delta. Green’s functions for Sturm-Liouville systems. **Solution Techniques for Linear Partial Differential Equations** Separation of variables. The use of integral transforms (Fourier’s sine, cosine and exponential transforms; the Laplace transform). Green’s functions. **Special Functions** Laplace’s equation in polar coordinates. Bessel and Legendre functions and their properties. Orthogonal expansions. **Calculus of Variations** Classical variational problems. The Euler-Lagrange equations and their use. Variational formulation of Sturm-Liouville systems and approximation of eigenvalues.

Learning and Teaching Methods	Lectures and tutorials.

Indicative Syllabus
1. Linear Ordinary Differential Equations 1.1) General theory of linear ordinary differential equations. Power series solutions and the method of Frobenius for second-order, linear, ordinary differential equations. The Dirac delta. Green's functions for Sturm-Liouville systems.
2. Solution Techniques for Linear Partial Differential Equations 2.1) Separation of variables. The use of integral transforms (Fourier's sine, cosine and exponential transforms; the Laplace transform). Green's functions.
3. Special Functions 3.1) Laplace's equation in polar coordinates. Bessel and Legendre functions and their properties. Orthogonal expansions.
4. Calculus of Variations 4.1) Classical variational problems. The Euler-Lagrange equations and their use. Variational formulation of Sturm-Liouville systems and approximation of eigenvalues.

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	demonstrate an understanding of the theory of linear ordinary differential equations
MLO2	select and use appropriate series expansions to solve second order linear ordinary differential equations
MLO3	calculate Green's functions and use them to solve Sturm-Liouville systems
MLO4	apply separation of variables to solve important linear partial differential equations (such as the wave equation, the heat equation and Laplace's equation) in tailored coordinate systems
MLO5	derive and demonstrate an understanding of the main properties of Bessel functions and Legendre polynomials
MLO6	calculate orthogonal expansions of simple functions
MLO7	use the Euler-Lagrange equations to solve variational problems
MLO8	use the calculus of variations to estimate eigenvalues of Sturm-Liouville systems.

Requisites

Assessment Threshold	There is a threshold of 35% on the main exam

Module Content & Assessment

Assessment Breakdown	%
Formal Examination	75.00%
Other Assessment(s)	25.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	75
Indicative Week	Week 14	**Learning Outcomes**	1,2,3,4,5,6,7,8
Assessment Threshold:	35	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
The main exam lasts for 2 hours

Other Assessment(s)

Assessment Type	In Class Test	**% of Total Mark for Module**	25
Indicative Week	See Student Handbook	**Learning Outcomes**	1,2,3,4
Assessment Threshold:	35	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
The in-class test consists of several compulsory problems

Module Activity

Part Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	111
Hours (up to 100 for 5 ECTS credits)	150.00

Recommended Reading List

Recommended Book Resources

S. Hassani. (2009), Mathematical Methods for Students of Physics and Related Fields, 2e. Springer-Verlag.

N.N. Lebedev. (1972), Special Functions and Their Applications, Dover Publications.

R. Weinstock. (1974), Calculus of Variations, Dover Publications.

Supplementary Book Resources

G.B. Arfken and H.J.Weber. (2005), Mathematical Methods for Physicists, 6e. Academic Press.

S. Hassani. (2002), Mathematical Physics – A Modern Introduction to its Foundations, Springer-Verlag.

M. Boas. (2005), Mathematical Methods in the Physical Sciences, 3e. Wiley.

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MATH 4843: Topics in Analysis 1

Module Details

Module Code:	MATH 4843
Module Long Title:	Topics in Analysis 1 APPROVED
Banner Title:	MATH 4843 Topics in Analysis 1
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Sept 2019 (September 2019)
Language of Instruction:	English
ECTS Credits::	7.5
ISCED Code:	0541 - Mathematics
Current Coordinator::	SUSAN LAZARUS
Module Coordinators:	SUSAN LAZARUS (06 December 2019 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	The learner is introduced to metric spaces, and shown how the notion of distance yields the concepts of convergence of sequences, closed sets and continuity. We study the concept of completeness, Banach's Fixed Point Theorem and its applications. Normed linear spaces are introduced, and in particular Banach Spaces.
Indicative Syllabus	**Metric Spaces** The axioms of a metric space, examples of metric spaces including function and sequence spaces, convergence, continuity, open and closed sets, completeness. **Banach's Fixed-point Theorem** Statement and proof of the theorem. Applications to differential equations and linear equations. **Normed Linear Spaces** The axioms of a normed linear space, examples of normed linear spaces, properties of a norm, Banach Spaces.
Learning and Teaching Methods	Lectures supported by tutorials

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	identify whether or not a given system is a metric space
MLO2	demonstrate an understanding of the properties of a distance function
MLO3	identify whether or not an algebraic structure satisfies the axioms of a normed linear space
MLO4	demonstrate an understanding of the properties of a norm function,
MLO5	be familiar and comfortable working with examples of normed linear spaces,
MLO6	identify whether or not a given sequences converges in a metric space or normed linear space,
MLO7	identify whether or not a metric space or normed linear space is complete,
MLO8	identify whether or not given functions on metric spaces or normed linear spaces are continuous,
MLO9	apply Banach’s Fixed Point Theorem to relevant applications.

Requisites

Module Content & Assessment

Assessment Breakdown	%
Formal Examination	75.00%
Other Assessment(s)	25.00%

Derogations from the General Assessment Regulations

Threshold of 35% on written exam

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	75
Indicative Week	Week 14	**Learning Outcomes**	1,2,3,4,5,6,7,8,9
Assessment Threshold:	35	**Assessment Role**	Not yet determined
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
End of Semester examination

Other Assessment(s)

Assessment Type	Practical Assignment	**% of Total Mark for Module**	25
Indicative Week	See Student Handbook	**Learning Outcomes**	1,2,3,4,5,6,7,8
Assessment Threshold:	None	**Assessment Role**	Not yet determined
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
Assignments

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	111
Hours (up to 100 for 5 ECTS credits)	150.00

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MATH 4841: Complex Analysis

Module Details

Module Code:	MATH 4841
Module Long Title:	Complex Analysis APPROVED
Banner Title:	Complex Analysis
Version:	1
Valid From:	Jan 2020 (January 2020)
Language of Instruction:	English
ECTS Credits::	7.5
ISCED Code:	0541 - Mathematics
Current Coordinator::	COLUM WATT
Module Coordinators:	COLUM WATT (07 January 2020 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	This module is devoted to the calculus of functions of a complex variable, that is, functions whose domain and range are regions of the complex plane rather than subsets of the real line. A grounding in functions of a complex variable is provided and the interplay between analytic and geometric factors in complex function theory is demonstrated. The module aims to develop the manipulative and reasoning skill of each student in this elegant and useful area of mathematics.
Indicative Syllabus	Review of complex numbers and their graphical representation. Manipulation of inequalities. Factorisation of complex polynomials. Contours, simple closed curves, open and connected subsets in the complex plane. **Analytic Functions** Functions of a complex variable, real and imaginary parts, differentiability. Analytic functions and the Cauchy-Riemann conditions. Laplace's equation: harmonic and conjugate harmonic functions. Polynomials, exponential, trigonometric, hyperbolic and logarithmic functions. **Complex Integration** Contour integrals, the Fundamental Theorem of Calculus, Cauchy's theorem, Cauchy's Integral Formula. Morera's theorem, Liouville's theorem and the Fundamental Theorem of Algebra. **Taylor and Laurent Series** Sequences, series and convergence in the complex plane. Power series: Taylor and Laurent series, uniform convergence of series. Classification of singularities and zeros. The Residue theorem and applications.

Learning and Teaching Methods	Lectures and tutorials.

Indicative Syllabus
1. Algebra and geometry of the complex plane 1.1) Review of complex numbers and their graphical representation. Manipulation of inequalities. Factorisation of complex polynomials. Contours, simple closed curves, open and connected subsets in the complex plane.
2. Analytic Functions 2.1) Functions of a complex variable, real and imaginary parts, differentiability. Analytic functions and the Cauchy-Riemann conditions. Laplace's equation: harmonic and conjugate harmonic functions. Polynomials, exponential, trigonometric, hyperbolic and logarithmic functions.
3. Complex Integration 3.1) Contour integrals, the Fundamental Theorem of Calculus, Cauchy's theorem, Cauchy's Integral Formula. Morera's theorem, Liouville's theorem and the Fundamental Theorem of Algebra.
4. Taylor and Laurent Series 4.1) Sequences, series and convergence in the complex plane. Power series: Taylor and Laurent series, uniform convergence of series. Classification of singularities and zeros. The Residue theorem and applications.

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	factor complex polynomials and manipulate inequalities involving complex variables
MLO2	demonstrate an understanding of the complex logarithm, exponential, trigonometric and hyperbolic functions and how they are related
MLO3	use the Cauchy-Riemann conditions to check for analyticity
MLO4	calculate the harmonic conjugate of a given harmonic function
MLO5	calculate contour integrals directly and, where appropriate, by the use of Cauchy's integral theorems
MLO6	Calculate Taylor and Laurent series and classify isolated zeros and singularities
MLO7	evaluate real integrals by the use of Cauchy's residue theorem
MLO8	use conformal mappings in the solution of Laplace's equation

Requisites

Assessment Threshold	There is a threshold of 35% on the main exam.

Module Content & Assessment

Assessment Breakdown	**%**
Formal Examination	75.00%
Other Assessment(s)	25.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	75
Indicative Week	Week 14	**Learning Outcomes**	1,2,3,4,5,6,7,8
Assessment Threshold:	35	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
The main examination lasts for 2 hours

Other Assessment(s)

Assessment Type	In Class Test	**% of Total Mark for Module**	25
Indicative Week	Week 7	**Learning Outcomes**	1,2,3,4,5
Assessment Threshold:	35	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
The in-class test consists of several compulsory problems.

Module Activity

Part Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	111
Hours (up to 100 for 5 ECTS credits)	150.00

Recommended Reading List

Recommended Book Resources

E.B. Saff and A.D. Snider. (2003), Fundamentals of Complex Analysis, 3e. Prentice Hall.

Supplementary Book Resources

J. Reade. (2003), Calculus with Complex Numbers, CRC Press.

J.W. Brown and R.V.Churchill. (2008), Complex Variables and Applications, McGraw-Hill.

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MATH 4844: Topics in Analysis 2

Module Details

Module Code:	MATH 4844
Module Long Title:	Topics in Analysis 2 APPROVED
Banner Title:	MATH 4844 Topics in Analysis 2
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Sept 2019 (September 2019)
Language of Instruction:	English
ECTS Credits::	7.5
ISCED Code:	0541 - Mathematics
Current Coordinator::	SUSAN LAZARUS
Module Coordinators:	SUSAN LAZARUS (06 December 2019 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	This is a continuation of the Topics in Analysis 1 module. We will study inner product spaces and Hilbert spaces, orthonormal bases, decomposition theorems for Hilbert spaces and an introduction to the theory of operators.
Indicative Syllabus	**Hilbert Spaces** Inner product spaces, orthogonality, orthonormal expansions, Fourier coefficients, Bessel's Theorem, Parseval's Relation, the Riesz-Fisher Theorem and orthogonal decomposition. **Theory of Operators** Bounded linear operators, linear functionals, dual spaces, the Riesz-Representation Theorem, the adjoint of an operator, self-adjoint operators, unitary operators.
Learning and Teaching Methods	Lectures supported by tutorials

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	identify whether or not an algebraic structure satisfies the axioms of an inner product space,
MLO2	work with inner products and their properties to prove results about inner product and normed linear spaces,
MLO3	demonstrate an understanding of Bessel's Theorem and Parseval's Relations and the applications of these results
MLO4	identify whether or not a given operator on a linear space is a linear operator,
MLO5	identify whether or not a given operator on a normed linear space is a bounded linear operator,
MLO6	be familiar with the space of bounded linear operators and comfortable working with the operator norm.
MLO7	find the adjoint of a given linear operator and determine if the operator is Hermitian, unitary and/or normal.

Requisites

Module Content & Assessment

Assessment Breakdown	%
Formal Examination	75.00%
Other Assessment(s)	25.00%

Derogations from the General Assessment Regulations

Threshold of 35% on written exam

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	75
Indicative Week	Week 14	**Learning Outcomes**	1,2,3,4,5,6,7
Assessment Threshold:	35	**Assessment Role**	Not yet determined
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
End of Semester written exam

Other Assessment(s)

Assessment Type	Practical Assignment	**% of Total Mark for Module**	25
Indicative Week	See Student Handbook	**Learning Outcomes**	1,2,3,4,5
Assessment Threshold:	None	**Assessment Role**	Not yet determined
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
Assignment

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	111
Hours (up to 100 for 5 ECTS credits)	150.00