Module MATH 4801 - Partial Differential Equations v1 (Year/Cycle:4 / Semester:Semester 1 / Delivery Type:Mandatory)

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MATH 4801: Partial Differential Equations

Module Details

Module Code:	MATH 4801
Module Long Title:	Partial Differential Equations APPROVED
Banner Title:	Partial Differential Equations
Version:	1
Valid From:	Sept 2019 (September 2019)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0541 - Mathematics
Current Coordinator::	DANA MACKEY
Module Coordinators:	DANA MACKEY (07 January 2020 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	This module is an introduction to the theory of Partial Differential Equations and their applications in the Physical Sciences. It builds on the knowledge gained in MATH 3802 (Ordinary Differential Equations) and makes extensive use of the methods and techniques introduced in that module.
Indicative Syllabus	First order partial differential equations (linear and quasi-linear). Conservation laws, characteristics and shocks. Traffic flow problems. Second order linear partial differential equations: classification into parabolic, hyperbolic and elliptic equations. Characteristics. Solving first and second order equations using Laplace transforms. The method of separation of variables. The heat, wave and Laplace equation with various boundary conditions and their applications to problems in physical sciences.
Learning and Teaching Methods	Lectures supported by problem-solving tutorials. Modelling examples from physics and engineering applications solved with the aid of mathematical software packages. Lectures: 2 hours/week Tutorials: 1 hour/week

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	Recognise and classify a wide range of first and second order linear partial differential equations and take the best approach for solving or analysing them
MLO2	Understand conservation laws and their physical significance, solutions with discontinuities and shocks
MLO3	Construct characteristics for first and second order equations and use them for finding solutions.
MLO4	Solve second order partial differential equations using Laplace transforms and separation of variables
MLO5	Construct and solve linear models for heat transfer and wave propagation problems

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
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**	25
Indicative Week	See Student Handbook	**Learning Outcomes**	1,2,3
Assessment Threshold:	None	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	61
Hours (up to 100 for 5 ECTS credits)	100.00

Recommended Reading List

Recommended Book Resources

L. Debnath. (1995), Integral Transforms and their Applications, CRC Press.

J. Ockendon, S. Howison, A. Lacey, A. Movchan. (1999), Applied Partial Differential Equations, Oxford University Press.

D. Kreider, R. Kuller, D. Ostberg, F. Perkins. (1966), An Introduction to Linear Analysis, Addison Wesley.

Module MATH 4824 - Project v1 (Year/Cycle:4 / Semester:Semester 1 & 2 / Delivery Type:Mandatory)

APPROVED

MATH 4824: Project

Module Details

Module Code:	MATH 4824
Module Long Title:	Project APPROVED
Banner Title:	Project
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Sept 2018 (September 2018)
Language of Instruction:	English
ECTS Credits::	15
ISCED Code:	0541 - Mathematics
Current Coordinator::	JOE CONDON
Module Coordinators:	JOE CONDON (12 April 2019 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	This module provides experience of undertaking a deep and rigorous investigation of a specific, advanced problem in mathematical sciences under the guidance of an academic supervisor. The module develops the broad range of skills required to perform a significant independent body of work. The learner will also be required to communicate their learning, understanding and knowledge discovery through presentations and a formal written document that describe the mathematical problem solving skills applied in their investigation and their scientifically justifiable conclusions. The module therefore requires developing a deep knowledge of a particular topic related to the learner's studies and skills in the acquisition, assimilation, and communication of scientific knowledge. The planning, execution and writing of the project requires the learner to appreciate the importance of literature review, project management, the interpretation of data and the concise, clear presentation of scientific information. The module therefore builds upon not only the technical knowledge acquired throughout the programme but also upon the skills developed in professional development, modelling and programming modules.
	Description & delivery: The content of the project undertaken will vary with the subject matter being investigated. However, the project must explore and describe sufficiently advanced mathematical subject material as to utilise and exploit discipline knowledge associated with the final stages of the programme and its technical content must be compatible with the expectations of an honours degree level research work in mathematical sciences or industrial mathematics. The presentation, technical prowess and mathematical level of the project will all contribute to its assessment and the content and quality of all submitted work is the responsibility of the learner. Project topics proposed by academic supervisors are allocated to learners at the start of the first semester and are reflective of the research interests of academic staff in the School, including industrial applications. Learners may propose their own topic in advance and these topics will be made available if they are judged appropriate and appropriate resources are available to provide supervision. Some project topics may be allocated to more than one learner if appropriate. The delivery of the project is principally via supervision meetings with an appointed academic project supervisor. These regular meetings will take place during the first semester and prior to submission in the second semester. The purpose of the meetings is to provide academic guidance to learners, introduce topics, discuss and monitor progress, facilitate understanding and provide feedback. Learners must attend scheduled meetings and are expected to be well prepared and to engage with supervisions constructively and professionally.

Indicative Syllabus	Learners will be required to attend group delivery sessions as notified and information pertinent to each particular year will be provided by the Stage Tutor. Information and topics communicated via these methods may include: project expectations e.g. conduct; written report requirements (length; mathematical content; document layout & presentation; academic writing & referencing); expectations for presentations; project planning, timekeeping and supervision etiquette; plagiarism. These objectives are supported by learners' prior learning of research tools and academic writing in professional development modules of earlier stages. Description of assessment methods: Plagiarism is extremely serious and will not be tolerated. Suspected plagiarism of any form will be dealt with in accordance with Programme and Institute practices. Learners will be assessed (as described in the section below) across all submitted material and their engagement, conduct and professionalism. Projects will be assessed for their originality, depth, complexity and substance, the professionalism of their presentation both written and in person and the conduct and understanding of the learner. Interim report & presentation: Prior to semester 2 learners will be required to submit an interim report and brief presentation. The report will be between 8 and 10 pages including a title page and appendices and will be written and presented formally. The School will provide detailed instructions on the submission of the report and the document requirements which include: a short written description and introduction to the project; a detailed work schedule for project elements and tasks; a sample of the project content using the formatting and style of the final project; a brief report of preliminary work undertaken (e.g. indicative table of contents, relevant software identified, summary of mathematics learning including references and bibliography, etc.). A brief individual presentation using presentation software based on this report describing their progress will be delivered by each learner followed by questions, discussion and feedback from members of the assessment panel. Written report: A written report will be prepared by the learner in clear academic English in the learner's own words. The School will provide detailed instructions on the submission of the report and on style: e. g. spacing; font size; length; structure (e.g cover page; abstract; table of contents; chapters following clearly demarcated themes with appropriate sections and subsections; conclusions and further work; references; appendices). Plagiarism guidelines for the programme are provided to the learner and will be strictly applied. The report will be formally written in an academic style appropriate to the mathematical sciences using appropriate professional typesetting software (e.g. Latex/MS word). Guidance and a standard template will provided. The document must be well structured: chapters, sections, subsections, equations, tables, figures, etc. will be numbered, captioned and cross-referenced. Equations must be consistently typeset (not included as images). Reference citations to prior work should be used throughout and a complete list of references and a bibliography of other sources should be included following one of the standard recognised formats (e.g. Harvard style). The report should be error free (including typographical and formatting errors) and will be assessed on the quality and clarity of its exposition in the context of the topic area, the refinement of its presentation and the originality, depth, technicality and mathematical scope of the content. Final Presentation: The learner will make a formal presentation of their work to academic staff using PDF/PowerPoint slides (or equivalent). The presentation should be academic in nature and summarise the objectives and findings of the work. Following the presentation, the learner will be required to answer questions from the assessment panel to demonstrate their understanding of the written material submitted. The presentation will be assessed on its quality, professionalism, engagement with the audience, technical content and the learner's ability to answer relevant questions appropriately.

Learning and Teaching Methods	The module is delivered over two semesters.

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	Apply and combine skills and advanced subject knowledge and techniques from a mathematical area (or areas) towards the exploration of one or more well-defined, challenging mathematical problems appropriate to the final stage of an honours degree in mathematical sciences or industrial mathematics.
MLO2	Demonstrate techniques of scientific enquiry in a specialised area (including a literature and software review as appropriate).
MLO3	Interpret and evaluate the literature in the context of a particular scientific topic and summarise other contributions.
MLO4	Reflect upon, organise, and effectively communicate key concepts from their work in a professional and original manner through written submissions and oral presentations.
MLO5	Draw conclusions on review topic and critically assess findings of their work.
MLO6	Write a substantial technical report using formal scientific language and structure, detailing the insights, discoveries and understanding of an advanced and challenging mathematical topic (appropriate to final year undergraduate learning in mathematical sciences) achieved during the project.
MLO7	Effectively plan and schedule delivery of a lengthy technical body of work delivered over a number of months.

Requisites

Assessment Threshold	A threshold of 35% will apply to component 4 of CA.

Module Content & Assessment

Assessment Breakdown	%
Other Assessment(s)	100.00%

Derogations from the General Assessment Regulations

Compensation will not apply to or from this module.

Assessments

Other Assessment(s)

Assessment Type	Project	**% of Total Mark for Module**	100
Indicative Week	Week 15	**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
Continuous Assessment:
Component 1: Interim report and presentation [20%]
Component 2: Final written report [50%]
Component 3: Conduct, understanding & initiative [10%]
Component 4: Final oral presentation and questions from assessment panel [20%]

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	20
Self Directed	280
Hours (up to 100 for 5 ECTS credits)	300.00

Module MATH 4805 - Algebraic Structures: Rings & Fields v1 (Year/Cycle:4 / Semester:Semester 1 / Delivery Type: Elective)

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MATH 4805: Algebraic Structures: Rings & Fields

Module Details

Module Code:	MATH 4805
Module Long Title:	Algebraic Structures: Rings & Fields APPROVED
Banner Title:	Algebraic Str.: Rings & Fields
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Sept 2018 (September 2018)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0541 - Mathematics
Current Coordinator::	FIONA MURRAY
Module Coordinators:	• SUSAN LAZARUS (11 April 2019 to 10 July 2023) • FIONA MURRAY (10 July 2023 to ---)
School Responsible:	School of Mathematics & Statistics
Campus:	City Campus
Module Overview	This module introduces the learner to the algebraic structures of Rings and Fields and to their application and uses within other scientific and mathematical areas.
Indicative Syllabus	**Ring Theory** Basic definitions and examples, homomorphisms, isomorphisms, ideals, quotient rings, polynomial rings, divisibility and factorisation, commutative rings, integral domains, principal ideal domains, quotient field. **Field Theory** Finite fields, extension fields, simple extensions, finite extensions, minimal polynomial, construction of finite fields, primitive elements, splitting fields.
Learning and Teaching Methods	Lectures and problem-solving sessions.

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	demonstrate an understanding of the different axiomatic structures of Rings, Integral Domains and Fields,
MLO2	demonstrate an understanding of the fundamental concepts involved in Ring Theory and Field Theory
MLO3	demonstrate familiarity with the many examples of the different algebraic structures and concepts discussed in class.

Requisites

Assessment Threshold	35% on Invigilated Examination

Module Content & Assessment

Assessment Breakdown	%
Formal Examination	70.00%
Other Assessment(s)	30.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	70
Indicative Week	Week 14	**Learning Outcomes**	1,2,3
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**	30
Indicative Week	Week 7	**Learning Outcomes**	1,3
Assessment Threshold:	None	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	61
Hours (up to 100 for 5 ECTS credits)	100.00

Module MATH 4802 - Applied Functional Analysis I v1 (Year/Cycle:4 / Semester:Semester 1 / Delivery Type:Elective)

APPROVED

MATH 4802: Applied Functional Analysis I

Module Details

Module Code:	MATH 4802
Module Long Title:	Applied Functional Analysis I APPROVED
Banner Title:	Applied Functional Analysis I
Version:	1
Valid From:	Semester 1 - 2009/10 (September 2009)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0541 - Mathematics
Current Coordinator::	MILENA VENKOVA-MCGARRAGHY
Module Coordinators:	MILENA VENKOVA-MCGARRAGHY (14 January 2022 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	This module introduces the theory of Banach spaces and their applications.
Indicative Syllabus	Normed spaces: definition, basic properties and examples. Banach spaces; finite- dimensional Banach spaces, continuous linear functionals on Banach spaces. Hahn-Banach Theorem. Separation Theorem and its applications in economics and in classification theory. Farcas' Lemma and its applications to linear programming. Continuous linear operators on Banach spaces, examples (differentiation, integral transforms). Norm of an operator, spaces of operators. Open mapping and closed graph theorems.
Learning and Teaching Methods	Lectures supported by tutorials

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	demonstrate knowledge of some key areas of functional analysis and be able to apply it.
MLO2	apply advanced mathematical reasoning abilities and some skills in the construction of proof.
MLO3	show awareness of the widespread applications of linear operators in mathematics and the physical sciences.

Requisites

Assessment Threshold	35%

Module Content & Assessment

Assessment Breakdown	%
Formal Examination	100.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	100
Indicative Week	See Student Handbook	**Learning Outcomes**	1,2,3
Assessment Threshold:	35	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	61
Hours (up to 100 for 5 ECTS credits)	100.00

Recommended Reading List

Recommended Book Resources

Erwin Kreyszig. (1991), Introductory Functional Analysis with Applications, John Wiley & Sons, p.704, [ISBN: 978-0471504597].

V.I. Lebedev. (1996), An Introduction to Functional Analysis in Computational Mathematics, Birkhäuser, p.256, [ISBN: 978-0817638887].

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MATH 4804: Coding Theory I

Module Details

Module Code:	MATH 4804
Module Long Title:	Coding Theory I APPROVED
Banner Title:	MATH 4804 Coding Theory I
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Sept 2018 (September 2018)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0541 - Mathematics
Current Coordinator::	SUSAN LAZARUS
Module Coordinators:	SUSAN LAZARUS (11 April 2019 to ---)
School Responsible:	School of Mathematics & Statistics
Campus:	City Campus
Module Overview	This module introduces the learner to the basic concepts of Coding Theory and Information Theory. We will study issues concerning encoding for efficiency and methods of coding source information in ways so as to detect and correct errors in transmission.
Indicative Syllabus	Basic definitions, efficient encoding, variable length codes, average codeword length, Huffman encoding, block codes, nearest neighbour decoding, Hamming distance, Error-detection and error-correction capabilities, vector spaces over the field of integers modulo a prime, linear codes, error correction in linear codes, the dual of a linear code, source encoding with a linear code.
Learning and Teaching Methods	Lectures supported by tutorials

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	demonstrate an understanding of the basic concepts of coding and information theory
MLO2	identify uniquely decipherable and instantaneous codes
MLO3	Compare the average codeword lengths of different encoding schemes
MLO4	produce the Huffman encoding scheme for a given source alphabet with a given probability distribution
MLO5	recognize the parameters of a code and identify if a code exists or not for given parameters
MLO6	demonstrate an understanding of the concept of a perfect code
MLO7	create new codes from given codes
MLO8	demonstrate an ability to calculate in a vector space over the field of integers modulo a prime
MLO9	demonstrate a familiarity with linear codes, their error correction and detection capabilities and their generator matrices
MLO10	Construct standard arrays for error correction within linear codes

Requisites

Module Content & Assessment

Assessment Breakdown	%
Formal Examination	100.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	100
Indicative Week	Week 14	**Learning Outcomes**	1,2,3,4,5,6,7,8,9,10
Assessment Threshold:	None	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	61
Hours (up to 100 for 5 ECTS credits)	100.00

Module MATH 4814 - Decision Theory and Games v1 (Year/Cycle:4 / Semester:Semester 1 / Delivery Type:Elective)

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MATH 4814: Decision Theory and Games

Module Details

Module Code:	MATH 4814
Module Long Title:	Decision Theory and Games APPROVED
Banner Title:	Decision Theory and Games
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Sept 2018 (September 2018)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0541 - Mathematics
Current Coordinator::	JOE CONDON
Module Coordinators:	JOE CONDON (12 April 2019 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	This module introduces the student to decision making and games theory. It covers the areas of decision making under certainty and under risk. These concepts are then expanded to include competitive decision making and the strategy of game play. Case studies of all models will be presented, formulated and solved using appropriate software.
Indicative Syllabus	How to make complex decisions under certainty: the Saaty scale and the analytic hierarchical process. Decisions under strict uncertainty: Maximax, Maximin, Hurwicz, Savage and Laplace criteria. Axioms of decision under strict uncertainty. Decisions under risk and expected return/utility. Decision trees: Imperfect information and Bayes Theoem, the value of imperfect information. Sensitivity analysis, one-way and two-way analyses. Threshold analysis. Concept of utility and utility theory. Lotteries, axioms of lotteries, reference gambles and assessing utilities using direct methods. Describing attitudes to risk – risk premium and risk aversion function. Game theory and games: strategic form for two person games. Two person zero sum games: pure and mixed strategy solutions. The concept of domination. Solutions for 2x2, 2 x N, N x 2 and N x N games. Formulation N x M games as a linear programming problem. Solution to N x M games using the simplex algorithm and interpretation of the results. Some concepts concerning non-zero sum games and definition of Nash equilibria.
Learning and Teaching Methods	Lectures supported by problem-solving sessions and the use of software packages.

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	To conduct a decision analysis under certainty using the analytic hierarchy process.
MLO2	Formulate decision problems under strict uncertainty and be able to analyse detailed decisions under risk using decision trees.
MLO3	Understand and apply sensitivity analysis and threshold analysis, and be able to apply both techniques to novel decision problems.
MLO4	Use software in decision tree analysis and understand the role of utility in decision making problems.
MLO5	Analyse two person zero-sum games of any dimension using the techniques of linear programming and in particular the simplex method.
MLO6	Understand the basics of two person non zero-sum games and Nash Equilibria.

Requisites

Module Content & Assessment

Assessment Breakdown	%
Formal Examination	100.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	100
Indicative Week	Week 15	**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
n/a

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	61
Hours (up to 100 for 5 ECTS credits)	100.00

Module MATH 4811 - Dynamical Systems and Chaos v1 (Year/Cycle:4 / Semester:Semester 1 / Delivery Type:Elective)

OLLSCOIL TEICNEOLAÍOCHTA BHAILE ÁTHA CLIATH
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MATH 4811: Dynamical Systems and Chaos

Module Details

Module Code:	MATH 4811
Module Long Title:	Dynamical Systems and Chaos APPROVED
Banner Title:	Dynamical Systems and Chaos
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Sept 2020 (September 2020)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0541 - Mathematics
Current Coordinator::	ROSSEN IVANOV
Module Coordinators:	ROSSEN IVANOV (23 October 2019 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	This course provides an introduction to applied dynamical systems and the qualitative study of differential equations. Dynamical systems are abundant in the physical world and include for example, the motion of the planets, the weather, electrical circuits and the behaviour of living organisms. Some systems like planetary motion are regular and predictable, while others such as the weather are believed to be chaotic in the sense that even small discrepancies in the initial state will inevitably result in huge discrepancies over time. This module builds upon the stage 3 ordinary differential equations module. Topics covered include Lyapunov stability, invariant manifolds, periodic orbits, bifurcations and chaos in dynamical systems. The motivation behind new concepts and their application to problems in science and engineering is emphasized.
Learning and Teaching Methods	Lectures supported by problem-solving sessions.
Rationale for Change :	To comply to the new format supported by the system – itemized syllabus and itemized reading list structure.

Indicative Syllabus
1. Linear dynamical systems 1.1) Introduction and preparatory material. Linear versus nonlinear systems. Equilibria, diagonalization, multiple eigenvalues, stability, stable, unstable, and center subspaces. Nonhomogeneous systems. Classification of planar systems.
2. Solutions of nonlinear dynamical systems 2.1) Solutions of initial value problems, existence and uniqueness of solutions, continuous dependence on initial conditions and parameters.
3. Linearization methods for nonlinear dynamical systems

3.1) Linearization, invariant manifolds. Stable, unstable and center manifolds. Hartman-Grobman theorem.
4. Lyapunov stability theory for nonlinear dynamical systems 4.1) Lyapunov functions. Stability and instability theorems. Exponential stability.
5. Global theory of nonlinear dynamical systems 5.1) Periodic orbits. Limit cycles, attractors. Poincaré-Bendixon theorem. Poincaré maps.
6. Bifurcation theory for nonlinear dynamical systems 6.1) Bifurcations of vector fields. Saddle-node, transcritical, pitchfork and Hopf bifurcations. Stability under perturbations. Structural stability.
7. Sensitivity to initial conditions 7.1) Density of periodic orbits. Chaos and strange attractors. Linking of periodic orbits.

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	demonstrate an understanding of mathematical basis of some models of dynamical systems
MLO2	analyse the global behaviour, stability and sensitivity of nonlinear systems
MLO3	demonstrate an insight into the complexity of nonlinear systems
MLO4	demonstrate knowledge and hands on experience on variety of interesting, inherently nonlinear examples.

Requisites

Assessment Threshold	N/A

Module Content & Assessment

Assessment Breakdown	**%**
Formal Examination	100.00%

Derogations from the General Assessment Regulations

None

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	100
Indicative Week	Week 15	**Learning Outcomes**	1,2,3,4
Assessment Threshold:	40	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
End-of-module examination

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	61
Hours (up to 100 for 5 ECTS credits)	100.00

Recommended Reading List

Recommended Book Resources

Morris W. Hirsch,Stephen Smale,Robert L. Devaney. (2013), Differential Equations, Dynamical Systems, and an Introduction to Chaos, 3. Elsevier, Oxford, p.418, [ISBN: 978-0-12-382010-5].

D. Arrowsmith,C.M. Place. (1992), Dynamical Systems, Chapman and Hall/CRC, p.330, [ISBN: 9780412390807].

Lawrence Perko. (2008), Differential Equations and Dynamical Systems, Springer Science & Business Media, p.557, [ISBN: 0-387-95116-4].

Supplementary Book Resources

Stephen Lynch. (2009), Dynamical Systems with Applications using MapleTM, Birkhäuser, p.500, [ISBN: 9780817643898].

Stephen Wiggins. (2006), Introduction to Applied Nonlinear Dynamical Systems and Chaos, Springer Science & Business Media, p.844, [ISBN: 978-0-387-21749-9].

John Guckenheimer,Philip Holmes. (2013), Nonlinear Oscillations, Dynamical Systems, and Bifurcations of Vector Fields, Springer Science & Business Media, p.462, [ISBN: 978-1-4612-1140-2].

Module MATH 4807 - Financial Mathematics I v1 (Year/Cycle:4 / Semester:Semester 1 / Delivery Type:Elective)

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MATH 4807: Financial Mathematics I

Module Details

Module Code:	MATH 4807
Module Long Title:	Financial Mathematics I APPROVED
Banner Title:	Financial Mathematics I
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Sept 2018 (September 2018)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0541 - Mathematics
Current Coordinator::	STEPHEN O SULLIVAN
Module Coordinators:	STEPHEN O SULLIVAN (20 October 2019 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.

Indicative Syllabus

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

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	Demonstrate the application of various concepts of hedging and pricing by arbitrage in a discrete time framework to problems.
MLO2	Price vanilla and exotic options within multi-step recombinant binomial models.
MLO3	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	100.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	100
Indicative Week	See Student Handbook	**Learning Outcomes**	1,2,3
Assessment Threshold:	None	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	61
Hours (up to 100 for 5 ECTS credits)	100.00

Module MATH 4803 - Fluid Mechanics v1 (Year/Cycle:4 / Semester:Semester 1 / Delivery Type:Elective)

APPROVED

MATH 4803: Fluid Mechanics

Module Details

Module Code:	MATH 4803
Module Long Title:	Fluid Mechanics APPROVED
Banner Title:	Fluid Mechanics
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Sept 2018 (September 2018)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0541 - Mathematics
Current Coordinator::	BRENDAN REDMOND
Module Coordinators:	• CHRIS HILLS (23 May 2019 to 28 March 2022) • BRENDAN REDMOND (28 March 2022 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	This module presents the basic and more advanced principles of fluid mechanics and illustrates them by application to a variety of problems of scientific interest. The aim of this module is to introduce the fundamental aspects of both classic and modern fluid mechanics and to provide techniques for solving specific classes of fluid flow problems. The module is suitable for stage 4 learners of the DT205/DT220 course or equivalent.
Indicative Syllabus	**Preliminaries:** Properties of fluids, dimensional reasoning, the continuum model, Newtonian fluids. **Fundamental Equations:** Conservation laws, the rate of strain matrix. Mathematical methods – vector differential calculus. **Flow Kinematics:** Acceleration of a fluid particle, flow lines, vorticity. **Solutions of the Navier Stokes Equations:** Couette flow, flow in a pipe, flow down an inclined plane.

	Slow Viscous Flows: The bi-harmonic equation and some solutions of it. **Water Waves:** Surface gravity waves, sinusoidal waves on deep water, particle paths for travelling waves.

Learning and Teaching Methods	Lectures are primarily used to impart module content to the learner, Problem solving sessions are designed to encourage learners to work both individually and in groups.

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	Demonstrate an understanding of the basic properties of fluids such as the no-slip condition
MLO2	Derive the equation of conservation of mass as applied to fluid motion
MLO3	Derive the formula for the acceleration of a fluid particle
MLO4	Derive the equations of the flow lines of a fluid for different velocity profiles
MLO5	Solve the Navier Stokes Equations for some simple flows such as flow in a pipe
MLO6	Derive the bi-harmonic equation and solve it under different conditions
MLO7	Solve some elementary problems on water waves

Requisites

Module Content & Assessment

Assessment Breakdown	%
Formal Examination	100.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	100
Indicative Week	See Student Handbook	**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

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	61
Hours (up to 100 for 5 ECTS credits)	100.00

Module MATH 4812 - Fourier Analysis and Wavelets v1 (Year/Cycle:4 / Semester:Semester 1 / Delivery Type:Elective)

APPROVED

MATH 4812: Fourier Analysis and Wavelets

Module Details

Module Code:	MATH 4812
Module Long Title:	Fourier Analysis and Wavelets APPROVED
Banner Title:	Fourier Analysis & Wavelets
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Sept 2020 (September 2020)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0541 - Mathematics
Current Coordinator::	ROSSEN IVANOV
Module Coordinators:	ROSSEN IVANOV (23 October 2019 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	Classical Fourier analysis and the modern theory of wavelets are widely used today in such applications as signals analysis and image processing. While the classical theory remains ideal for the analysis and processing of periodic phenomena, the use of wavelets is much more efficient in connection with irregular and fractal structures. This module provides a careful balance between the underlying theory and the practical algorithms which are used in applications.
Learning and Teaching Methods	Lectures supported by tutorials
Rationale for Change :	To comply to the new format supported by the system – itemized syllabus and itemized reading list structure.

Indicative Syllabus
1. Fourier Analysis 1.1) Review of Fourier series. Fourier transforms, inversion, convolution product, Parseval's identity, Fourier transforms of Gaussians. Physical interpretation: spectral content of a signal.
2. Wavelets 2.1) Physical motivation: deficiencies of Fourier transforms, Wavelet functions, translations, dilations, Wavelet series and transforms, orthonormal families, Window functions and their parameters, Time-frequency analysis, the Uncertainty Principle, Inverse formulae and duals, Examples of spline-wavelets.

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	broaden their knowledge of Fourier analysis.
MLO2	understand the concepts underlying the theory of wavelets, and the importance of the theory in applications, as a significant refinement of the methods of Fourier analysis.
MLO3	apply the basic properties of Fourier series and transforms, in particular, those that are relevant to wavelets.
MLO4	apply theory of wavelets to signal analysis problems.

Requisites		
Requisite Type	***Module Title***	***Type***
Pre Requisite	MATH 3804 v.2 Real Analysis [Approved]	Module

Assessment Threshold	40%

Module Content & Assessment

Assessment Breakdown	**%**
Formal Examination	100.00%

Derogations from the General Assessment Regulations
N/A

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	100
Indicative Week	Week 15	**Learning Outcomes**	1,2,3,4
Assessment Threshold:	40	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
End of semester examination

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	61
Hours (up to 100 for 5 ECTS credits)	100.00

Recommended Reading List

Recommended Book Resources

Charles K. Chui. (2016), An Introduction to Wavelets, Elsevier, p.278, [ISBN: 9781483282862].

Supplementary Book Resources

Jayakumar Ramanathan. (2012), Methods of Applied Fourier Analysis, Birkhäuser, p.329, [ISBN: 9781461272670].

Kenneth B. Howell. (2016), Principles of Fourier Analysis, Second Edition, CRC Press, p.788, [ISBN: 9781498734097].

Yves Nievergelt. (1999), Wavelets Made Easy, Springer Science & Business Media, p.297, [ISBN: 978-0817640613].

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APPROVED

MATH 4809: Linear Programming

Module Details

Module Code:	MATH 4809
Module Long Title:	Linear Programming APPROVED
Banner Title:	Linear Programming
Version:	1
Valid From:	Jan 2019 (January 2019)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0541 - Mathematics
Current Coordinator::	SARAH MORRIS
Module Coordinators:	SARAH MORRIS (13 June 2019 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	This module expands on the fundamental concepts of linear programming covered in MATH 2804. It introduces artificial variables as a means to finding an initial basic feasible solution, and the concept of duality. The fundamental theorem of linear programming and the theory behind the simplex method are presented. Case studies will be presented, formulated and solved using appropriate software.
Indicative Syllabus	Linear Programming Concepts Feasible, basic feasible and optimal solutions. The fundamental theorem of linear programming. Simplex method (tableau) Standard form, canonical form. Basic and nonbasic variables, pivot rows and columns, ratio test. Artificial variables, tests for optimality. Revised Simplex Matrix and vector form, reduced costs, ratio tests. Duality Marginal costs/prices, formulations, weak duality theorem, strong duality theorem. Sensitivity Analysis Finding parameter ranges using revised Simplex and relationships of the primal and the dual, solving problems relating to economic analysis. Complementary Slackness Quantifying the relationship between the primal/dual slack variables and dual/primal slack variables, proving optimality of primal/dual.
Learning and Teaching	Lectures supported by tutorials

Methods	

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	Solve any linear program using the Simplex method using tableau
MLO2	Solve linear programs using the revised Simplex method
MLO3	Understand the underlying concepts of duality
MLO4	Solve linear programs using the dual simplex
MLO5	Solve problems using sensitivity analysis
MLO6	Use complementary slackness to find dual solutions

Requisites

Module Content & Assessment

Assessment Breakdown	%
Formal Examination	100.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	100
Indicative Week	Week 14	**Learning Outcomes**	1,2,3,4,5,6
Assessment Threshold:	35	**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)*
Lecture	100
Hours (up to 100 for 5 ECTS credits)	100.00

Module MATH 4806 - Numerical Analysis v1 (Year/Cycle:4 / Semester:Semester 1 / Delivery Type:Elective)

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MATH 4806: Numerical Analysis

Module Details

Module Code:	MATH 4806
Module Long Title:	Numerical Analysis APPROVED
Banner Title:	Numerical Analysis
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Jan 2019 (January 2019)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0541 - Mathematics
Current Coordinator::	JOHN BUTLER
Module Coordinators:	JOHN BUTLER (13 June 2019 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	The aim of this module is to equip the learner with the knowledge necessary to effectively select and implement finite-difference methods for the numerical integration of differential equations. During the first part of the module the learner will be introduced to the theory and practice of common techniques for the numerical integration of ordinary differential equations with initial conditions. The second part of the module will focus on numerical methods for partial differential equations. iPython notebooks (or equivalent) will be used to implement numerical methods.
Indicative Syllabus	Ordinary Differential Equations Linear systems; Finite-differencing techniques; Stability analysis; Explicit Runge-Kutta methods; Adaptive stepsize control, Convergence analysis. Boundary Value Problems: Shooting method, non-linear shooting method, finite difference schemes, Partial Differential Equations; Finite-differencing; Parabolic Equations: Heat equation; Crank-Nicolson method, implicit and explicit methods Hyberbolic Equations: Advection equation; Courant Friedrichs Lewy condition Elliptic Equations: Poisson equation, five point scheme.
	The module will be delivered through lectures and tutorials. This will be supplemented with time in the computer laboratory.

Learning and Teaching Methods	In addition, students will be required to undertake background reading and self-directed learning. Modules are also typically supported by tutorial sheets, example classes and, laboratory sessions. The self-directed learning hours will be devoted to preparing for lectures, undertaking solutions to example sheets, reflecting upon the lecture material, refining and deepening understanding and consolidating individual learning. Modules may be supported by online material and delivery and computer laboratory sessions. Where online delivery takes place this may substitute for some contact hours.

Indicative Syllabus
1. Ordinary Differential Equations Linear systems 1.1) Finite-differencing techniques; Stability analysis; Explicit Runge-Kutta methods; Adaptive stepsize control, Convergence analysis. 1.2) Boundary Value Problems: Shooting method, non-linear shooting method, finite difference schemes.
2. Partial Differential Equations; Finite-differencing 2.1) Parabolic Equations: Heat equation; Crank-Nicolson method, implicit and explicit methods 2.2) Hyberbolic Equations: Advection equation; Courant Friedrichs Lewy condition 2.3) Elliptic Equations: Poisson equation, five point scheme.

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	Derive and apply a range of finite difference methods for solving differential equations for initial value problems.
MLO2	Describe the stability, consistency, and convergence properties of various numerical integration schemes for boundary value problems
MLO3	Explain the differences between various numerical methods for the integration of linear partial differential equations and identify the conditions under which they are an appropriate choice.
MLO4	Use numerical packages to solve differential equations and interpret the results

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
Assessment Threshold:	35	**Assessment Role**	Not yet determined
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 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)*
Lecture	39
Self Directed	61
Hours (up to 100 for 5 ECTS credits)	100.00

Recommended Reading List

Recommended Book Resources

Richard L. Burden,J. Douglas Faires,Annette M. Burden. (2015), Numerical Analysis, Cengage Learning, p.912, [ISBN: 1305253663].

Brian Bradie. (2006), A Friendly Introduction to Numerical Analysis, Prentice Hall, p.933, [ISBN: 0130130540].

Supplementary Book Resources

J. Stoer,R. Bulirsch. (2013), Introduction to Numerical Analysis, Springer Science & Business Media, p.746, [ISBN: 978-0-387-21738-3].

Gordon D. Smith,Gordon D.. Smith,Smith, Gordon Dennis Smith. (1985), Numerical Solution of Partial Differential Equations, Oxford University Press, p.337, [ISBN: 0198596502].

J.R. Dormand. (1996), Numerical Methods for Differential Equations, CRC Press, p.384, [ISBN: 0849394333].

QUALITY OFFICE

MATH 4813: Quantum Mechanics I

Module Details

Module Code:	MATH 4813
Module Long Title:	Quantum Mechanics I QUALITY OFFICE
Version:	1
Valid From:	Sept 2019 (September 2019)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	- -Not Set-
Current Coordinator::	EMIL MIHAYLOV PRODANOV
Module Coordinators:	EMIL MIHAYLOV PRODANOV (22 October 2019 to ---)
School Responsible:	School of Mathematics & Statistics
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 problem solving sessions

Indicative Syllabus
1. The Wave Function 1.1) The Schrödinger equation. Statistical interpretation. Probability. Normalization. Momentum. The Uncertainty Principle.
2. Time-independent Schrödinger Equation 2.1) Stationary states. The infinite square well. The harmonic oscillator. The free particle. 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	understand the principles and formalism of quantum theory.
MLO2	be able to solve simple quantum mechanical systems.
MLO3	be aware of the applications of quantum mechanics in modern theoretical physics.

Requisites		
Requisite Type	***Module Title***	***Type***
Pre Requisite	MATH 3806 v.1 Classical Mechanics [Approved]	Module

Module Content & Assessment

Assessment Breakdown	%
Formal Examination	100.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	100
Indicative Week	Week 14	**Learning Outcomes**	1,2,3
Assessment Threshold:	40	**Assessment Role**	Not yet determined
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
Final exam

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	61
Hours (up to 100 for 5 ECTS credits)	100.00

Recommended Reading List

Recommended Book Resources

David J. Griffiths. (2017), Introduction to Quantum Mechanics, Cambridge University Press, p.468, [ISBN: 978-1107179868].

Supplementary Book Resources

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

Eugen Merzbacher. (1998), Quantum Mechanics, John Wiley & Sons, p.672, [ISBN: 978-0-471-88702-7].

Module MATH 4825 - Queueing Theory and Markov Processes v2 (Year/Cycle:4 / Semester:Semester 1 / Delivery Type:Elective)

APPROVED

MATH 4825: Queueing Theory and Markov Processes

Module Details

Module Code:	MATH 4825
Module Long Title:	Queueing Theory and Markov Processes APPROVED
Banner Title:	Queueing & Markov Processes
Version:	2
Indicative NFQ level:	Level 8
Valid From:	Sept 2023 (September 2023)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0541 - Mathematics
Current Coordinator::	BLATHNAID SHERIDAN
Module Coordinators:	BLATHNAID SHERIDAN (27 July 2023 to ---)
School Responsible:	School of Mathematics & Statistics
Campus:	City Campus
Module Overview	This module builds and expands upon the material covered in queueing theory and Markov processes in Stage 2. It introduces the concept of multiple server models and variable arrival and service rates. It introduces the learner to the topic of Markov processes and its applications and to the formulation and solution of related models. Case studies of both topics are covered.
Indicative Syllabus	
Learning and Teaching Methods	Lectures supported by problem-solving and tutorial sessions.

Indicative Syllabus
1. Queueing models 1.1) Introduction to queueing models. Poisson arrival patterns and exponential service times.
2. Types of queues & queue behaviour 2.1) Single and multiple servers, infinite and finite capacity. Balking and reneging.
3. Steady-state solutions 3.1) Derivation of steady-state solutions for various queueing systems.

4. Queueing system performance measures 4.1) Derivation and analysis of mean queueing times, mean number of customers in the queue.
5. Markov chains 5.1) Definition of Markov chains and their properties.
6. State space formulation for Markov chains 6.1) Formulation of a Markov chain and properties and use of transition matrices.
7. Classification 7.1) Classification of states of a Markov chain
8. Limiting distributions 8.1) Derive limiting distributions of a Markov chain.

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	Derive the generalised Poisson queueing model.
MLO2	Apply the basic single/multiple server model with Poisson input, exponential service rate, identical parallel servers, infinite/finite system capacity and infinite calling population.
MLO3	Calculate queueing system performance measures including mean queueing times, mean number of customers and utilisation rates.
MLO4	Formulate queueing systems where the arrival rates and departure rates are state-dependent.
MLO5	Apply queueing theory to sample problems.
MLO6	Explain the Markov process.
MLO7	Classify the individual states of a Markov chain and explain the properties of a Markov chain.
MLO8	Derive the limiting distribution of a Markov chain.

Requisites

Assessment Threshold	Examination: 35%

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 15	**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
End of semester examination

Other Assessment(s)

Assessment Type	In Class Test	**% of Total Mark for Module**	25
Indicative Week	See Student Handbook	**Learning Outcomes**	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)*
Lecture	39
Self Directed	61
Hours (up to 100 for 5 ECTS credits)	100.00

Recommended Reading List

Recommended Book Resources

Hamdy A. Taha. (2016), Operations Research, Pearson Higher Education, [ISBN: 9781292165547].

Frederick S. Hillier,Gerald J. Lieberman. Introduction to Operations Research, [ISBN: 9781259253188].

Supplementary Book Resources

Bernard W. Taylor. Introduction to Management Science, Global Edition, [ISBN: 9781292092911].

Barry Render,Ralph M. Stair,Michael E. Hanna. Quantitative Analysis for Management, [ISBN: 9780137129904].

Module MATH 4808 - Regression Models I v1 (Year/Cycle:4 / Semester:Semester 1 / Delivery Type:Elective)

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MATH 4808: Regression Models I

Module Details

Module Code:	MATH 4808
Module Long Title:	Regression Models I APPROVED
Banner Title:	MATH 4808 Regression Modelling
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Sept 2018 (September 2018)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0541 - Mathematics
Current Coordinator::	JOE CONDON
Module Coordinators:	JOE CONDON (12 April 2019 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	The aim of this module is to introduce the student to multiple linear and generalised linear regression models. The statistical theory regarding these models, point and interval estimation for parameters and predicted responses is covered. Model building techniques are critically examined. Methods for residual and influence diagnostics are introduced. The R software system (or equivalent) will be explored as a tool for fitting these models.
Indicative Syllabus	Motivation and formulation of the multiple regression model. Least squares (LS) and the multiple linear regression model. Variance of parameter estimates and fitted values, confidence intervals and hypothesis testing. General linear hypotheses and ANOVA. Model building techniques, residual and inference diagnostics and their role in model appraisal. Including categorical predictors in regression. Generalised linear models (GLM): the exponential family; likelihood for GLMs including the linear, logistic and Poisson regression models. Fitting GLMs. Interpretation of model parameters; general linear hypotheses of parameters. Wald's and likelihood ratio tests; model building techniques.
Learning and Teaching Methods	Lectures supported by problem-solving sessions and the use of the R statistical software package (or equivalent).

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	Formulate and fit multiple linear regression models.
MLO2	Understand and utilise hypothesis testing within the general linear hypothesis framework.
MLO3	Fit a mixture of multiple predictor and polynomial models to novel data sets using software and correctly extract the relevant results from the software.
MLO4	Apply and critically appraise classical and modern regression model building techniques.
MLO5	Perform model critiques using regression and influence diagnostics.
MLO6	Effectively apply model building algorithms using software and produce diagnostic plots and other outputs.
MLO7	Include categorical predictors in regression models, with and without interactions and formulate ANOVA models in the multiple regression framework.
MLO8	Fit and interpret general linear models that include a mixture of continuous and categorical predictors and their interactions.
MLO9	Formulate, fit and interpret the output from generalised linear models (GLM: in particular logistic and Poisson regression).
MLO10	Use model building techniques to identify candidate GLM models, including hypothesis testing and information criteria approaches.

Requisites

Assessment Threshold	Examination: 35%

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 15	**Learning Outcomes**	1,2,3,4,5,6,7,8,9,10
Assessment Threshold:	35	**Assessment Role**	Not yet determined
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Other Assessment(s)

Assessment Type	In Class Test	**% of Total Mark for Module**	25
Indicative Week	Week 6	**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)*
Lecture	39
Self Directed	61
Hours (up to 100 for 5 ECTS credits)	100.00

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MATH 4816: Applied Functional Analysis II

Module Details

Module Code:	MATH 4816
Module Long Title:	Applied Functional Analysis II APPROVED
Banner Title:	Applied Functional Analysis II
Version:	1
Valid From:	Semester 1 - 2009/10 (September 2009)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0541 - Mathematics
Current Coordinator::	MILENA VENKOVA-MCGARRAGHY
Module Coordinators:	MILENA VENKOVA-MCGARRAGHY (14 January 2022 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	This module continues the development of rigorous integration theory and provides an elementary introduction to Hilbert spaces. It provides a sound foundation in analysis for students wishing to continue their mathematical studies at graduate level.
Indicative Syllabus	Hilbert spaces. Inner products, the Cauchy-Schwartz inequality, orthogonality. Fourier series with respect to an orthonormal basis, applications to solving differential equations. Parseval's theorem and its application to the Fourier transform. Orthogonal complements and projections; best approximations and its applications in numerical analysis. Riesz's representation theorem, braket notation. Bounded linear operators on a Hilbert space. Introduction to Spectral theory: eigenvalues and eigenvectors, spectrum, spectral radius. Neumann series, the spectral radius as a "measure" of an operator, applications to convergence of iterative algorithms. Mathematical formulation of quantum mechanics.

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	demonstrate knowledge of some key areas of functional analysis and be able to apply it;
MLO2	use advanced mathematical reasoning and some skills in the construction of proof;
MLO3	show awareness of the widespread applications of Hilbert spaces in mathematics and the physical sciences.

Requisites

Assessment Threshold	35%

Module Content & Assessment

Assessment Breakdown	%
Formal Examination	100.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	100
Indicative Week	Week 1	**Learning Outcomes**	1,2,3
Assessment Threshold:	35	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	61
Hours (up to 100 for 5 ECTS credits)	100.00

Recommended Reading List

Recommended Book Resources

Erwin Kreyszig. (1991), Introductory Functional Analysis with Applications, John Wiley & Sons, p.704, [ISBN: 978-0471504597].

V.I. Lebedev. (1996), An Introduction to Functional Analysis in Computational Mathematics, Birkhäuser, p.256, [ISBN: 978-0817638887].

Module MATH 4827 - Case Studies in Industrial Modelling v1 (Year/Cycle:4 / Semester:Semester 2 / Delivery Type: Elective)

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MATH 4827: Case Studies in Industrial Modelling

Module Details

Module Code:	MATH 4827
Module Long Title:	Case Studies in Industrial Modelling APPROVED
Banner Title:	Case Studies in Industrial Modelling
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Jan 2019 (January 2019)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0541 - Mathematics
Current Coordinator::	FIONA MURRAY
Module Coordinators:	FIONA MURRAY (16 May 2019 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	This module will present examples of mathematical models arising from practical problems in technological settings. For each case study, all stages of modelling will be discussed, including model formulation, mathematical analysis, numerical simulation and visualization of solutions. It aims to introduce and familiarize students with mathematical research which is problem oriented instead of topic oriented; to give students experience with formulating and analysing mathematical models.
Learning and Teaching Methods	Extensive problem solving sessions supported by lectures presenting relevant material and use of a mathematical software package (MAPLE/R).

Indicative Syllabus
1. Mathematical Modelling 1.1) The process of mathematical modelling: Scaling techniques and non-dimensionalization; Physical conservation laws.
2. Asymptotic methods 2.1) A short introduction to Asymptotic methods.
3. Dynamical systems 3.1) A short introduction to dynamical systems methods.
4. Case Studies 4.1) Problem solving through case studies.

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	Formulate real-world problems in mathematical terms.
MLO2	Integrate methods and skills from various mathematical areas studied in the past and apply them towards the solution of a problem.

Requisites

Assessment Threshold	A student must attain 40% or higher is each task component to pass this module. Internal compensation will be allowed between task components provided, (a) the compensated mark is 35% or more, and (b) the compensating markexceeds 40% by at least twice the deficiency in the compensated mark.

Module Content & Assessment

Assessment Breakdown	**%**
Other Assessment(s)	100.00%

Assessments

Other Assessment(s)

Assessment Type	Case Study	**% of Total Mark for Module**	100
Indicative Week	See Student Handbook	**Learning Outcomes**	1,2
Assessment Threshold:	None	**Assessment Role**	Not yet determined
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
Typically, 3 separate case studies.

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	61
Hours (up to 100 for 5 ECTS credits)	100.00

Recommended Reading List

Recommended Book Resources

Glenn Fulford,Glenn R. Fulford,Philip Broadbridge. (2002), Industrial Mathematics, Cambridge University Press, [ISBN: 9780521001816].

Sam Howison. (2005), Practical Applied Mathematics, Cambridge University Press, [ISBN: 9780521603690].

Module MATH 4822 - Coding Theory II v1 (Year/Cycle:4 / Semester:Semester 2 / Delivery Type:Elective)

APPROVED

MATH 4822: Coding Theory II

Module Details

Module Code:	MATH 4822
Module Long Title:	Coding Theory II APPROVED
Banner Title:	Coding Theory II
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Jan 2019 (January 2019)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0540 - Mathematics and statistics not further defined or elsewhere classified
Current Coordinator::	SUSAN LAZARUS
Module Coordinators:	SUSAN LAZARUS (22 October 2019 to ---)
School Responsible:	School of Mathematics & Statistics
Campus:	City Campus
Module Overview	This module continues the study of Coding Theory, with particular emphasis on linear codes and cyclic codes. We will study some special codes, in particular Hamming codes.
Indicative Syllabus	Revision of linear codes, dual of a linear code, parity check matrix, syndrome decoding, cyclic codes, Hamming codes, BCH codes, entropy, Shannon's theorem, perfect codes and the sphere-packing condition, the main coding theory problem.
Learning and Teaching Methods	Lectures supported by tutorials.

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	use the inner product on pairs of strings in the vector space over the integers modulo a prime and identify orthogonal pairs of strings,
MLO2	identify the orthogonal complement of a subset of strings,
MLO3	create and identify the dual code of a given linear code,
MLO4	determine the minimum distance of a code from its parity check matrix,
MLO5	construct syndrome tables for a linear code
MLO6	bring a generator matrix into left standard form,
MLO7	identify cyclic codes,
MLO8	use Hamming matrices for decoding

Requisites		
Requisite Type	***Module Title***	***Type***
Pre Requisite	MATH 4804 v.1 Coding Theory I [Approved]	Module

Module Content & Assessment

Assessment Breakdown	%
Formal Examination	100.00%

Assessments

Formal Examination			
Assessment Type	Written Examination	**% of Total Mark for Module**	100
Indicative Week	Week 14	**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 End of term examination			

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	61
Hours (up to 100 for 5 ECTS credits)	100.00

Module MATH 4817 - Cryptology v2 (Year/Cycle:4 / Semester:Semester 2 / Delivery Type:Elective)

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APPROVED
MATH 4817: Cryptology

Module Details

Module Code:	MATH 4817
Module Long Title:	Cryptology APPROVED
Banner Title:	Cryptology
Version:	2
Indicative NFQ level:	Level 8
Valid From:	Sept 2023 (September 2023)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0541 - Mathematics
Current Coordinator::	FIONA MURRAY
Module Coordinators:	FIONA MURRAY (27 July 2023 to ---)
School Responsible:	School of Mathematics & Statistics
Campus:	City Campus
Module Overview	This module introduces the learner to the basic concepts of Cryptology and the applications of Number Theory and Algebra to Cryptosystems.
Indicative Syllabus	**Classic Cryptology:** Some simple cryptosystems, shift and affine transformations, enciphering matrices. **Public Key Cryptology** : The idea of Public Key Cryptology, Finite Fields, Euler Phi Function, Chinese Remainder Theorem, Fermat and Euler Theorems, Discrete Logarithms, Modular Exponentiation, RSA Encryption. Basics of Elliptic curves and their applications to Cryptography.
Learning and Teaching Methods	Lectures supported by problem-solving sessions.

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	Demonstrate an understanding of the basic concepts of Cryptology.
MLO2	Understand the mathematics behind classical cryptosystems.
MLO3	Demonstrate an understanding of Public Key Cryptology.
MLO4	Understand the mathematics behind Public Key Cryptology.
MLO5	Encrypt and decrypt simple 1- and 2-dimensional affine cryptosystems.
MLO6	Encrypt and decrypt messages using RSA.
MLO7	Define elliptic curves, calculate the group of points of an elliptic curve.
MLO8	Explain the use of elliptic curves in public key cryptography.
MLO9	Encrypt and decrypt using an elliptic curve cryptosystem.

Requisites

Assessment Threshold	Examination 35%

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:	None	**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**	25
Indicative Week	See Student Handbook	**Learning Outcomes**	1,2,3,4,5
Assessment Threshold:	None	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	61
Hours (up to 100 for 5 ECTS credits)	100.00

Module MATH 4815 - Differential and Integral Equations v1 (Year/Cycle:4 / Semester:Semester 2 / Delivery Type: Elective)

APPROVED

MATH 4815: Differential and Integral Equations

Module Details

Module Code:	MATH 4815
Module Long Title:	Differential and Integral Equations APPROVED
Banner Title:	Differential & Integral Equats
Version:	1
Valid From:	Jan 2020 (January 2020)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0541 - Mathematics
Current Coordinator::	DANA MACKEY
Module Coordinators:	DANA MACKEY (07 January 2020 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	This module extends the material covered in MATH 4801 (Partial Differential Equations) and MATH 3802 (Ordinary Differential Equations) by introducing further topics and solution methods for Partial and Ordinary Differential Equations. It also introduces theoretical concepts from Integral Equations and some of their applications.
Indicative Syllabus	Introduction to Fourier transforms (exponential, sine, cosine and finite). Applications of Fourier transforms to solving ordinary and partial differential equations. The heat, wave and Laplace equations in spherical and cylindrical coordinates. Introduction to linear Volterra and Fredholm integral equations. Equivalence to ordinary differential equations. Solution of separable equations by integral transforms. The method of successive approximations and resolvent kernel for Volterra equations. The Fredholm Alternative. Applications of integral equations.
Learning and Teaching Methods	Lectures supported by problem-solving tutorials. Modelling examples from physics and engineering applications solved with the aid of mathematical software packages. Lectures: 2 hours/week Tutorials: 1 hour/week

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	Use Fourier transforms for solving a wide range of differential and integral equations
MLO2	Formulate and solve initial and boundary value problems for the heat and wave equations in spherical and cylindrical coordinates
MLO3	Solve linear Volterra and Fredholm integral equations using appropriate methods
MLO4	Understand the relationship between integral and differential equations and transform one type into another

Requisites

Assessment Threshold	35% End of semester 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 28	**Learning Outcomes**	1,2,3,4
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**	25
Indicative Week	See Student Handbook	**Learning Outcomes**	1,2
Assessment Threshold:	None	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	61
Hours (up to 100 for 5 ECTS credits)	100.00

Recommended Reading List

Recommended Book Resources

A. Jerri. (1985), Introduction to Integral Equations with Applications,, Marcel Dekker Inc..

L. Debnath. (1995), Integral Transforms and their Applications, CRC Press.

Module MATH 4818 - Financial Mathematics II v1 (Year/Cycle:4 / Semester:Semester 2 / Delivery Type:Elective)

APPROVED

MATH 4818: Financial Mathematics II

Module Details

Module Code:	MATH 4818
Module Long Title:	Financial Mathematics II APPROVED
Banner Title:	Financial Mathematics II
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Jan 2019 (January 2019)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0541 - Mathematics
Current Coordinator::	STEPHEN O SULLIVAN
Module Coordinators:	STEPHEN O SULLIVAN (20 October 2019 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.

Indicative Syllabus

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

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	Characterize and identify Wiener processes.
MLO2	Establish and apply Ito’s lemma.
MLO3	Treat expectations under change-of-measure.
MLO4	Derive and manipulate the Black-Scholes formula and Black-Scholes equation.
MLO5	Demonstrate Monte-Carlo numerical methods for option pricing.

Requisites		
Requisite Type	***Module Title***	***Type***
Pre Requisite	MATH 4807 v.1 Financial Mathematics I [Approved]	Module

Module Content & Assessment

Assessment Breakdown	%
Formal Examination	100.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	100
Indicative Week	See Student Handbook	**Learning Outcomes**	1,2,3,4,5
Assessment Threshold:	None	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	61
Hours (up to 100 for 5 ECTS credits)	100.00

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MATH 4821: Industrial Statistics: Survival Analysis

Module Details

Module Code:	MATH 4821
Module Long Title:	Industrial Statistics: Survival Analysis APPROVED
Banner Title:	Indus&Com Stats:Survival Analy
Version:	1
Valid From:	Jan 2019 (January 2019)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0542 - Statistics
Current Coordinator::	ALBERTO CAIMO
Module Coordinators:	ALBERTO CAIMO (13 May 2019 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	This module introduces the techniques of survival analysis and proportional hazards modelling. These techniques are used in diverse areas such as medicine, engineering (reliability analysis), actuarial science, sociology (event history analysis) and business / economics (duration analysis / time-to-event analysis). The module introduces the student to the special features of survival data such as censoring and positive skew in the distribution of survival times. Fundamental concepts of survival analysis will be introduced including the survivor function, the hazard function and the hazard ratio. The course will build from some nonparametric techniques such as the Kaplan-Meier estimate of the survival curve to parametric and non-parametric (i.e., Cox) proportional hazards models – some of the most flexible and widely used tools for the analysis of survival data.
Indicative Syllabus	**Introduction to survival data:** Features of survival data, distribution of survival times, survivor function, hazard function, cumulative hazard function. **Nonparametric procedures:** Estimating the survivor function: life-table, Kaplan-Meier, Nelson-Aalen, confidence intervals. Estimating the hazard function, estimating median and percentile survival and confidence intervals. Comparing two groups of survival data, the log-rank and Wilcoxon tests. Comparison of k-groups of survival data. **Parametric procedures:** Exponential, Weibull and log-normal models. Estimating survivor and hazard functions. Likelihood methods for estimating parameters from censored data. Including covariates and factors and hypothesis testing. Model building, Wald tests, likelihood ratio tests and nested models.

	The Cox model: The Cox proportional hazard model, baseline hazard function, hazard ratio, including covariates and factors, maximum likelihood for the Cox model. Treatment of ties in the Cox model. Confidence intervals for the Cox model regression parameters and hypothesis testing. Estimating the baseline hazard.

Learning and Teaching Methods	Lectures supported by tutorials and computer lab. sessions.

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	Understand the special features of survival data such as censoring and the role of the survivor, hazard and cumulative hazard functions in describing survival data and the relationship between these core functions.
MLO2	Perform non-parametric analysis of survival data using life-table, Kaplan-Meier, Nelson-Aalen techniques and compute confidence intervals for the survivor function.
MLO3	Formulate and fit parametric survival models using the exponential, Weibull and log-normal distributions, including hypothesis tests of parameters and confidence intervals. Fit proportional hazards models including covariates and factors and interpret the output from fitting such models using R/SAS.
MLO4	Formulate and fit proportional hazards models including covariates and factors using the Cox model. Perform hypothesis testing and model building. Interpret the output from fitting such models using R /SAS.
MLO5	Use R/SAS (or equivalent) for survival data analysis, applying techniques covered in the module.

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	See Student Handbook	**Learning Outcomes**	1,2,3,4,5
Assessment Threshold:	35	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
End of semester exam

Other Assessment(s)

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

Assessment Description
Continuous assessment

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	69
Self Directed	31
Hours (up to 100 for 5 ECTS credits)	100.00

Module MATH 4820 - Integer Programming v1 (Year/Cycle:4 / Semester:Semester 2 / Delivery Type:Elective)

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MATH 4820: Integer Programming

Module Details

Module Code:	MATH 4820
Module Long Title:	Integer Programming APPROVED
Banner Title:	Integer Programming
Version:	1
Valid From:	Sept 2019 (September 2019)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0541 - Mathematics
Current Coordinator::	SARAH MORRIS
Module Coordinators:	SARAH MORRIS (21 October 2019 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	This module expands on the fundamental concepts of Operations Research and Linear Programming. This module introduces a number of Integer Programming methods, including branch and bound, cutting planes, and network simplex.
Indicative Syllabus	Definition of Integer Programming Formulations, discrete/integer, types(network, transportation, location problems, set covering). Greedy algorithms Knapsack, travelling salesman heuristic, location problems. Branch and bound algorithm Linear relaxation, fathoming, branching, incumbent solution, discrete/ integer problems. Cutting plane methods Redundancy, tightening methods. Network Simplex Independence, basic feasible solutions, basic/nonbasic arcs, algorithm, optimality tests.
Learning and Teaching Methods	Lectures supported by tutorials

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	Explain the unique nature of integer programming and how solution methods differ from those of linear programming.
MLO2	Solve integer programs by branch and bound method.
MLO3	Demonstrate an understanding of relaxation in the context of integer programming
MLO4	Apply algorithms to solve the travelling salesman problem
MLO5	Solve problems using the network simplex algorithm
MLO6	Use cutting plane methods to iteratively

Requisites

Assessment Threshold	40%

Module Content & Assessment

Assessment Breakdown	**%**
Formal Examination	100.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	100
Indicative Week	See Student Handbook	**Learning Outcomes**	1,2,3,4,5,6
Assessment Threshold:	40	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	100
Hours (up to 100 for 5 ECTS credits)	100.00

APPROVED

MATH 4823: Nonlinear Programming

Module Details

Module Code:	MATH 4823
Module Long Title:	Nonlinear Programming APPROVED
Banner Title:	Nonlinear Programming
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Sept 2019 (September 2019)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0541 - Mathematics
Current Coordinator::	SARAH MORRIS
Module Coordinators:	SARAH MORRIS (23 October 2019 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	This module expands on the fundamental concepts of Operations Research and Linear Programming covered in MATH 2804 and MATH 4809. This module introduces a number of non-linear Programming models, including descent methods, conjugate gradient methods, quasi-newton methods, primal methods, and penalty and barrier methods. Case studies of models will be presented
Indicative Syllabus	**Unconstrained Optimisation:** Optimality conditions. Descent methods: line search, Newton's, Golden section search, Fibonacci, secant. Cauchy's steepest descent Conjugate gradient methods Non-differentiable optimization Quasi-newton method

	Constrained Optimisation: Optimality conditions Primal methods Penalty and barrier methods Case studies

Learning and Teaching Methods	Lectures and tutorials

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	Formulate and solve unconstrained non-linear optimization problems using descent methods, including golden search, Fibonacci, gradient methods, and steepest descent methods.
MLO2	Formulate and solve unconstrained non-linear optimization problems using conjugate gradient methods.
MLO3	Formulate and solve unconstrained non-linear optimization problems using quasi-newton methods.
MLO4	Formulate and solve constrained non-linear optimization problems using primal methods and penalty and barrier methods.

Requisites

Module Content & Assessment

Assessment Breakdown	%
Formal Examination	100.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	100
Indicative Week	See Student Handbook	**Learning Outcomes**	1,2,3,4
Assessment Threshold:	40	**Assessment Role**	Individual
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
Written exam

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	24
Tutorial	12
Self Directed	64
Hours (up to 100 for 5 ECTS credits)	100.00

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QUALITY OFFICE

MATH 4826: Quantum Mechanics II

Module Details

Module Code:	MATH 4826
Module Long Title:	Quantum Mechanics II QUALITY OFFICE
Version:	1
Valid From:	Sept 2019 (September 2019)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	- -Not Set-
Current Coordinator::	EMIL MIHAYLOV PRODANOV
Module Coordinators:	EMIL MIHAYLOV PRODANOV (21 October 2019 to ---)
School Responsible:	School of Mathematics & Statistics
Campus:	City Campus
Module Overview	Thus module is a continuation of Quantum Mechanics I and presents Quantum Mechanics from a mathematical perspective. The aims of this module are: - to build on the the mathematical description of Quantum Mechanics previously learnt in part I, - to introduce the student to the theory of the angular momentum in Quantum Mechanics, - to provide thorough knowledge of Quantum Dynamics.
Learning and Teaching Methods	Lectures supported by tutorials

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	Have deep understanding of the concept of angluar momentum in Quantum Mechanics.
MLO2	Fully understand the realization of physical observables as Hermitian operators acting in the space of physical states.
MLO3	Have deep knowledge on compatibility and measurement.
MLO4	Have full confidence when applying the principles of algebraic approaches to selected quantum mechanical problems.
MLO5	Being able to fit quantum mechanics in the wider picture of physics and mathematics and thoroughly understand the interplay between Quantum Mechanics and other major branches – classical mechanics, linear algebra, group theory, functional analysis.
MLO6	Have working knowledge on the mathematical apparatus of quantum mechanics.
MLO7	Being able to mathematically formulate quantum mechanics in both Schroedinger's and Heisenberg's formulation.

Requisites		
Requisite Type	***Module Title***	***Type***
Pre Requisite	MATH 3806 v.1 Classical Mechanics [Approved]	Module
Pre Requisite	MATH 4813 v.1 Quantum Mechanics I [Quality Office]	Module

Module Content & Assessment

Assessment Breakdown	**%**
Formal Examination	100.00%

Assessments

Formal Examination

Assessment Type	Written Examination	**% of Total Mark for Module**	100
Indicative Week	Week 30	**Learning Outcomes**	1,2,3,4,5,6,7
Assessment Threshold:	40	**Assessment Role**	Not yet determined
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
Final Exam

Module Activity

Full Time hours per semester	
Activity Type	*Duration (Hours)*
Lecture	39
Self Directed	61
Hours (up to 100 for 5 ECTS credits)	100.00

Recommended Reading List

Recommended Book Resources

Jun John Sakurai,Jim Napolitano. (2011), Modern Quantum Mechanics, Addison Wesley Longman, p.550, [ISBN: 0805382914].

Supplementary Book Resources

David Jeffery Griffiths,Professor David J Griffiths. (2005), Introduction to Quantum Mechanics, Addison-Wesley, p.468, [ISBN: 0131118928].

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

Module MATH 4819 - Regression Models II v1 (Year/Cycle:4 / Semester:Semester 2 / Delivery Type:Elective)

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MATH 4819: Regression Models II

Module Details

Module Code:	MATH 4819
Module Long Title:	Regression Models II APPROVED
Banner Title:	Regression Models II
Version:	1
Indicative NFQ level:	Level 8
Valid From:	Sept 2018 (September 2018)
Language of Instruction:	English
ECTS Credits::	5
ISCED Code:	0541 - Mathematics
Current Coordinator::	JOE CONDON
Module Coordinators:	JOE CONDON (12 April 2019 to ---)
School Responsible:	School of Mathematical Sciences (CC)
Campus:	City Campus
Module Overview	The aim of this module is to introduce the student to the analysis of data from designed experiments using the multiple regression formulation. To introduce the analysis of repeated measures data and other correlated data structures within a regression framework. The R software system (or equivalent) will be explored as a tool for fitting these models. This module expands on the treatment of the multiple linear regression model, introduced in MATH4808, to include classical experimental design models. Advanced topics such as repeated measures and other correlated data structures are considered using estimated generalised least squares and random effects.
Indicative Syllabus	Review of the multiple linear regression model including categorical predictors. Analysis of completely randomised design – the balanced and unbalanced cases – general linear hypothesis. Multiple comparisons and least squares means. Randomised block design, motives and methods. Two way designs – main effects and factorial models. Testing for interaction and interpretation. Extensions to three or more factors and simple fractional factorials Generalised least squares and estimated generalised least squares for repeated measures and other correlated data structures.

	Random effects and mixed modelling.

Learning and Teaching Methods	Lectures supported by problem-solving sessions and the use of the R statistical software package (or equivalent).

Learning Outcomes	
Upon successful completion of this module the learner will be able to	
#	
MLO1	Formulate and fit completely randomised experimental designs within the multiple linear regression framework.
MLO2	Understand and utilise hypothesis testing within the general linear hypothesis framework as a model for comparing treatment levels.
MLO3	Apply a number of multiple comparison techniques to the analysis of experimental data including specialised linear models techniques and more general p-value adjustment techniques (e.g. step-up/step-down methods).
MLO4	Apply effective analyses of two factor and higher order experiments including the balanced and unbalances cases, main effects and full factorial models.
MLO5	Perform effective analyses of experimental data using software.
MLO6	Understand the extension of the analyses of designed experiments to include correlated responses within the generalised least squares (GLS) paradigm.
MLO7	Use likelihood methods to formulate various correlated data structures, including cluster data and repeated measures.
MLO8	Interpret correlation parameter estimates from GLS.
MLO9	Formulate and fit random effects and linear mixed models as effective tools in the analysis of both correlated data and random factors/covariates.
MLO10	Effectively use software to fit and interpret GLS and linear mixed models.

Requisites

Assessment Threshold	Final written examination 35%

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 15	**Learning Outcomes**	1,2,3,4,5,6,7,8,9,10
Assessment Threshold:	35	**Assessment Role**	Not yet determined
Assessment Authenticity	Not Online	**Pass/Fail**	No

Assessment Description
n/a

Other Assessment(s)

Assessment Type	In Class Test	**% of Total Mark for Module**	25
Indicative Week	Week 6	**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)*
Lecture	39
Self Directed	61
Hours (up to 100 for 5 ECTS credits)	100.00