



**FLORIDA INTERNATIONAL UNIVERSITY
UNIVERSITY CURRICULUM COMMITTEE**

Proposal for a New Course

DO NOT TYPE IN THIS BOX
Bulletin # : 3
Academic Year : 2023-2024

1. **School/College** Engineering and Computing
Div./Dept. in Which Taught Knight Foundation School of Computing and Information Sciences

2. **COT** 4 3 **CIP Code (Leave this blank):** _____
Alpha Prefix 1st Digit Last 3 Digits "C"-lec-lab "L"-Lab Cr. Hrs.

3. **Grading Method (select one):** Graded Pass/Fail

4a. **Course Title** Introduction to Quantum Information and Probability

b. **Abbreviated course Title (for computer class schedules, transcripts)** Intro to Quantum Info
LIMITED TO 25 Characters (including spaces)

5. **Statewide Course Numbering Subject Matter Area** Computation Theory (COT)

6. **Catalog Description/Major Topics (not to exceed 200 characters including spaces)**
College of Medicine and College of Law: Attach description not exceeding 1,000 characters including spaces.

Introduction to quantum information theory and probability; Introduction to quantum error correction, communication, and security.

7. **Attach detailed syllabus course outline and course justification on separate page(s).**

8. **Prerequisite(s):** (COT 3100 or MAD 2104) and (STA 2023 or STA 2122 or STA 3033)

9. **Corequisite(s):** _____

10. **Objective(s) of Course:**

Describe fundamental concepts in quantum information theory
Discuss quantum channel capacity
Design quantum error correction codes
Discuss secure quantum key distribution

11. **Does this course duplicate/overlap other courses at FIU?** No Yes
If yes, please explain: _____

12. **What other closely related department(s) have been consulted about this course?**

13. **Is this course used for the assessment of a program or a certificate (if yes, then send a notification to assessment@fiu.edu)?** X No Yes

PROPOSAL REQUESTED BY:

Faculty Contact Farhad Shirani Chaharsooghi Farhad Shirani 10 / 12 / 2023
(Type name) (Signature)
fshirani@fiu.edu 305-348-8036
(Email address) (Phone number)

Chairperson (Dept./Div.) Jason Liu [Signature] 11 / 1 / 2023
(Type name) (Signature)

Chairperson (Curr. Comm.) Alexander Afanasyev [Signature] 11 / 15 / 2023
(Type name) (Signature)

College/School Dean Mark Weiss, Assoc Dean Mark Weiss 11 / 17 / 2023
(Type name) (Signature)

Submit one original form. Attach one copy of the course justification and course syllabus, course description, objectives, major topics and textbooks.

Subject: RE: Introducing Two New Courses on Quantum Information and Probability

From: Deidra Hodges <dhodges@fiu.edu>

Date: 10/31/2023, 2:19 PM

To: Farhad Shirani Chaharsooghi <fshirani@fiu.edu>

CC: Jason Liu <liux@fiu.edu>, Nagarajan Prabakar <prabakar@cis.fiu.edu>, sadjadiATcs <sadjadi@cs.fiu.edu>, Ou Bai <obai@fiu.edu>, Nezhir Pala <npala@fiu.edu>, Aleksandr Krasnok <akrasnok@fiu.edu>, Armando Barreto <barretoa@fiu.edu>, Vladimir Pozdin <vpozdin@fiu.edu>

Hi Dr. Chaharsooghi,

Thank you for sharing your proposals. I have reviewed them and am glad to see you had the review of Dr. Krasnok. We support your proposals and we look forward to our students being able to take these courses. We look forward to collaborative efforts!

Thanks again,

Deidra

Deidra R. Hodges, Ph.D.

ECE Department Chair, Associate Professor

Department of Electrical and Computer Engineering

College of Engineering and Computing, EC 3984

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From: Farhad Shirani Chaharsooghi <fshirani@fiu.edu>

Sent: Monday, October 30, 2023 11:59 AM

To: Deidra Hodges <dhodges@fiu.edu>

Cc: Jason Liu <liux@fiu.edu>; Nagarajan Prabakar <prabakar@cis.fiu.edu>; sadjadiATcs <sadjadi@cs.fiu.edu>

Subject: Introducing Two New Courses on Quantum Information and Probability

Dear Professor Hodges,

I hope that this email finds you well.

I am writing this email about two courses on 'Quantum Information and Probability' which I am planning to introduce, one in the undergraduate level and one in the graduate level.

I have attached the course proposals and other relevant documents to this email.

These course proposals have completed the departmental review processes in the corresponding committees at KFSICS. Furthermore, I have sought feedback, and received valuable positive input, from Professor Alex Krasnok at the ECE Department, along with several other faculty members in the field, regarding the course composition and contents.

I would be grateful for any additional comments and feedback from the faculty at the ECE department on these course proposals. I am very excited about the prospect of introducing these courses in the coming

academic year, and hope that these along with other quantum courses offered at our university will facilitate student training, and formation of strong research groups in various quantum research areas, which in turn would augment ongoing collaborative efforts on attracting funding and producing quality research in this area.

Thank you for your time and consideration.

Best regards,
Farhad Shirani

Farhad Shirani
Assistant Professor
Knight Foundation School of Computing and Information Sciences
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Course 4XXX Introduction to Quantum Information and Probability

New Course Justification

Quantum information is an emerging topic with significant recent interest and a vibrant and growing industry. Training computer science graduates with expertise in this field will provide them with bright professional prospects in an area of significant national interest.

Topics covered include: Linear algebra fundamentals; postulates of quantum mechanics; quantum probability models; quantum circuits and gates; introduction to entanglement, teleportation and Bell's inequality; introduction to quantum error-correcting codes; quantum communications (as time-permits); secure quantum key distribution.

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Course Title: Introduction to Quantum Information and Probability **Date:** 18/03/23

Course Number: COT 4XXX

Number of Credits: 3

Subject Area: Foundations	Subject Area Coordinator: Hadi Amini email: amini@cs.fiu.edu
Catalog Description: This course introduces basic concepts in quantum probability, quantum information, and an introduction to quantum error correction, communication, and security.	
Textbook: Quantum Computation and Quantum Information: 10th Anniversary Edition Authors: Michael A. Nielsen, Isaac L. Chuang ISBN-10: 9781107002173	
References: Printed lecture notes will be provided.	
Prerequisites: (COT 3100 or MAD 2104) and (STA 2023 or STA 2122 or STA 3033)	

Type: Elective for CS (Foundations group) and CY

Prerequisites Topics:

- Boolean algebra
- Linear Algebra
- Probability Theory

Course Outcomes:

1. Perform matrix operations, trace operations, and tensor operations [Applying]
2. State the axioms of quantum mechanics [Remember]
3. Explain quantum superposition, entanglement, teleportation, and the uncertainty principle [Understanding]
4. Compare the concepts of Shannon entropy for classical sources with the Von Neuman entropy of quantum sources. [Analyzing]
5. Evaluate and quantify quantum uncertainty and channel capacity [Evaluating]
6. Design quantum error correction codes for secure communication over quantum channels. [Creating]

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Introduction to Quantum Information and Probability

Association between Student Outcomes and Course Outcomes

BS in Computing: Student Outcomes	Course Outcomes
1) Analyze a complex computing problem and to apply principles of computing and other relevant disciplines to identify solutions.	1,2,3
2) Design, implement, and evaluate a computing-based solution to meet a given set of computing requirements in the context of the program's discipline.	4,5,6
3) Communicate effectively in a variety of professional contexts.	
4) Recognize professional responsibilities and make informed judgments in computing practice based on legal and ethical principles.	
5) Function effectively as a member or leader of a team engaged in activities appropriate to the program's discipline.	
Program Specific Student Outcomes	
6) Apply computer science theory and software development fundamentals to produce computing-based solutions. [CS]	6
6) Apply security principles and practices to maintain operations in the presence of risks and threats. [CY]	6

Assessment Plan for the Course and how Data in the Course are used to assess Student Outcomes

Student and Instructor Course Outcome Surveys are administered at the conclusion of each offering, and are evaluated as described in the School's Assessment Plan:
<https://abet.cis.fiu.edu/>

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 Introduction to Quantum Information and Probability

Outline

Topic	No. of Lecture Hours	Outcome
<ul style="list-style-type: none"> • Basics of Probability and Linear Algebra <ul style="list-style-type: none"> ○ Matrices, matrix operations, and traces ○ Random Variables ○ Joint Distributions and Conditional Distributions ○ Tensor Products 	6	1
<ul style="list-style-type: none"> • Axioms of Quantum Mechanics <ul style="list-style-type: none"> ○ Quantum States and State Spaces ○ State Evolution ○ Projective and General Measurements ○ Composite State Spaces 	4	2
<ul style="list-style-type: none"> • Quantum Gates, Circuits and Protocols <ul style="list-style-type: none"> ○ Classical vs Quantum Gates ○ Quantum Teleportation and Superdense Coding ○ Quantum entanglement and the Bell state ○ No Cloning Principle 	4	3
<ul style="list-style-type: none"> • Quantum Information and Probability <ul style="list-style-type: none"> ○ Uncertainty Principle and Quantum Ensemble ○ Purification ○ Quantum Conditional Probability ○ Von Neuman Entropy 	5	3, 4
<ul style="list-style-type: none"> • Quantum Channels <ul style="list-style-type: none"> ○ Classical-Quantum Channels ○ Quantum-Quantum Channels ○ Quantum Security 	3	5, 6
<ul style="list-style-type: none"> • Introduction to Quantum Channel Capacity <ul style="list-style-type: none"> ○ Classical Channel Capacity ○ Quantum Channel Capacity Formulation and Examples 	4	5
<ul style="list-style-type: none"> • Quantum Error Correction <ul style="list-style-type: none"> ○ Bit-flip channel and Phase flip-channel ○ CSS Code ○ Decoding CSS Code 	4	5,6

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 Introduction to Quantum Information and Probability

Course Outcomes Emphasized in Laboratory Projects / Assignments

	Outcome	Number of Weeks
1	Linear Algebra and Probability Theory Review Exercises Outcomes: 1	3
2	Axioms of Quantum Mechanics Exercises Outcomes: 2,3	4
3	Quantum Information and Entropy Exercises Outcomes: 3,4	4
4	Quantum Capacity Evaluation Outcomes: 5,6	2
5	Design of CSS Code Outcomes: 5,6	2

Oral and Written Communication: No significant coverage

Number of written reports:

Approximate number of pages for each report:

Number of required oral presentations:

Approximate time for each presentation:

Social and Ethical Implications of Computing Topics
 No significant coverage

Topic	Class time	Student performance measures

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Theoretical Contents

Topic	Class time
Probability Theory	4.5 Hours
Linear algebra	4.5 Hours

Problem Analysis Experiences

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The Coverage of Knowledge Units within Computer Science Body of Knowledge¹

Knowledge Unit	Topic	Lecture Hours
DS. Discrete Probability	1	4.5
IAS. Linear Algebra	1	4.5
IAS. Quantum Cryptography	5,7	3
IAS. Entropy Measures	4	7.5
AR/SF. Logic Gates	4	6

¹ See the latest version of Computer Science Curricula (2013). Final Report of the IEEE and ACM Joint Task Force on Computing Curricula, available at:
https://www.acm.org/binaries/content/assets/education/cs2013_web_final.pdf

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Performance Measures for Evaluation

All assignments are assigned through the Canvas course website. Please note that the deadlines are strictly enforced. For example, if the deadline is 11:59 PM, any assignment submitted after this time is considered late. It is also each student's responsibility to submit correct files and ensure the submission is successful before the deadline (please double check your Canvas submissions). If you are unable to submit your assignment through Canvas, please email a copy of your assignment to your instructor before the stated deadline. There will be a midterm and a final exam. Each exam will be cumulative with an emphasis on the most recently covered material.

Assignment	Total Points	Percentage of Final Grade
Quiz (11-Drop-1)	10 each	15%
Homework Assignments (2)	100 Each	15%
Midterm Exam	100	30%
Final Exam	100	40%
Total Course Grade		100%

Letter Grade Distribution

Letter	Range%	Letter	Range%	Letter	Range%
A	93 or above	B	82 – 85.9	C	70 – 73.9
A-	90 – 92.9	B-	78 – 81.9	D	60 – 69.9
B+	86 – 89.9	C+	74 – 77.9	F	Less than 60

Description of Possible Homework Activities

Homework 1: Axioms of Quantum Mechanics, Quantum Gates, Circuits, and Protocols

Description: This assignment aims to help students apply the skills they've acquired from the beginning of the course through Topic 3 (Quantum Gates, Circuits and Protocols), focusing on understanding the foundations of quantum mechanics and quantum information.

Tasks:

- 1) Quantum State Preparation and Manipulation:
 - Explain the concept of quantum state evolution.
 - Solve exercises on state transformation using unitary operations.

- 2) Linear Algebra and Probability in Quantum Systems:
 - Perform matrix operations and calculate traces for given quantum states.
 - Define random variables in a quantum context and contrast them with classical random variables.

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- Compute joint and conditional distributions for a set of quantum states.
 - Illustrate the use of tensor products in describing composite quantum systems.
- 3) Axioms of Quantum Mechanics Applications:
- Discuss projective measurements, general measurements, and their outcomes on quantum states.
 - Describe the structure of composite state spaces and the implications for quantum information processing.
- 4) Quantum Gates, Circuits, and Protocols:
- Contrast classical gates with their quantum counterparts. Demonstrate the functioning of basic quantum gates through matrix representation and effect on quantum states.
 - Provide a step-by-step explanation of quantum teleportation and superdense coding protocols.
 - Discuss quantum entanglement, specifically the formation and properties of the Bell state.
 - Explain the no cloning principle and its fundamental importance in quantum computing.

Deliverables:

A comprehensive report including solutions to homework problems with a detailed explanations of the quantum states and operations used. Matrix calculations, probability distributions, and tensor products associated with the tasks. Application of the axioms of quantum mechanics to the selected quantum states. Insights gained from the quantum gates, circuits, and protocols exercises.

Criteria	Excellent (100)	Good (80)	Average (60)	Below Average (40)	Poor (20)	Weight
State Preparation and Manipulation	demonstrating a deep understanding of superposition and state evolution principles.	Minor errors, showing good understanding of principles.	Some misunderstanding of the principles.	significant lack of understanding of principles.	No understanding of the principles.	20%
Linear Algebra and Probability	Mastery in performing complex matrix operations, traces, and probability computations in a quantum context.	Proficient in matrix operations and understanding quantum probability.	Basic understanding and application of linear algebra and probability in quantum systems.	Limited understanding with errors in matrix operations and probability calculations.	No understanding or incorrect application of linear algebra and probability in a quantum context.	20%
Axioms of Quantum Mechanics	Exceptional application and explanation of quantum axioms, including state spaces and projective measurements.	Good application and understanding of quantum axioms with minor inaccuracies.	Adequate understanding and application of quantum axioms with some inaccuracies.	Poor application of quantum axioms with significant misunderstandings.	Incorrect application or complete lack of understanding of quantum axioms.	30%
Quantum Gates & Protocols	Demonstrates advanced knowledge and practical application of quantum gates, circuits, and protocols.	Demonstrates good knowledge with some practical application errors.	Basic knowledge of quantum gates and protocols with several practical application errors.	Limited knowledge and application of quantum gates and protocols.	No knowledge or incorrect application of quantum gates and protocols.	30%

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Homework 2: Quantum Information, Channel Capacity, and Quantum Error Correction

Description: This assignment is intended to provide students with a comprehensive understanding of quantum information theory, the capacity of quantum channels, and the principles of quantum error correction. Students will apply knowledge from the beginning of the course through these advanced topics, focusing on the manipulation and transmission of quantum information with an emphasis on robustness against channel errors.

Tasks:

- 1) Quantum Information and Probability:
 - Conduct exercises on the purification of mixed states to obtain pure states.
 - Calculate quantum conditional probabilities and discuss their interpretations.
 - Compute Von Neumann entropy for different quantum states and discuss its significance.
- 2) Quantum Channels:
 - Compare classical-quantum channels with quantum-quantum channels, detailing the differences and applications.
 - Explore the concept of quantum security and its importance in information theory.
- 3) Introduction to Quantum Channel Capacity:
 - Review classical channel capacity and its limitations.
 - Formulate the quantum channel capacity and solve examples.
- 4) Quantum Error Correction:
 - Solve problems involving bit-flip and phase-flip channels and understand their impact on quantum states.
 - Learn to construct and apply CSS codes for quantum error correction.
 - Perform decoding of CSS codes and assess their effectiveness in error correction.

Deliverables:

A detailed report including Solutions to assigned problems with thorough explanations of quantum information theory concepts used. Calculations and discussions on quantum channel capacities and the implications for communication systems. Demonstrations of quantum error correction techniques and their practical applications.

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Criteria	Excellent (100)	Good (80)	Average (60)	Below Average (40)	Poor (20)	Weight
Quantum Information and Probability	Demonstrates exceptional understanding and application of the Uncertainty Principle, quantum ensembles, and entropy.	Demonstrates good comprehension with minor inaccuracies in application.	Shows a basic grasp of concepts with some errors in application.	Has limited understanding with significant errors in application.	Demonstrates no understanding or incorrect application of concepts.	20%
Quantum Channels	Provides a comprehensive analysis of quantum channels.	Provides a clear analysis with minor gaps in the analysis.	Offers a basic analysis with notable gaps in understanding.	Provides a flawed analysis with major misunderstandings of quantum channels.	Fails to provide a meaningful understanding.	25%
Quantum Channel Capacity	Masterfully formulates quantum channel capacity with practical examples showcasing in-depth understanding.	Formulates capacity with some errors but shows a good understanding of practical implications.	Has a basic understanding with errors in the formulation and practical examples.	Demonstrates limited grasp of channel capacity with significant errors in examples.	Incorrectly formulates channel capacity with no practical understanding or examples.	25%
Quantum Error Correction	Expertly solves error correction problems and perfectly applies CSS codes with comprehensive understanding.	Correctly applies error correction techniques with minor errors in problem solving.	Adequately applies techniques with some errors in understanding and problem solving.	Limited in applying error correction techniques with numerous errors in problem solving.	Unable to apply error correction techniques or solve related problems correctly.	30%