Course Title: Introduction to Quantum Information Science

Course number: ECE 445/545; PHYS 480/581

Term: Fall 2024

Instructor: Milad Marvian (mmarvian@unm.edu)

Time: Tuesdays & Thursdays 13:30-14:45

Location: TBD

Credit hours: 3

Office hours: TBD; request additional hours by email.
Zoom: https://unm.zoom.us/my/marvian
My office: ECE 235-D

Midterm date (tentative): Oct 24, 2024

Prerequisites: No prior knowledge of quantum mechanics is required. A background in linear algebra with familiarity with fundamental concepts such as vector spaces, linear transformations, eigenvalues, and eigenvectors (at the level of ECE300: advanced engineering mathematics is sufficient.

Course Description:

Although more than a hundred years have passed since the development of quantum mechanics, only relatively recently the significant potential of harnessing "weird" quantum phenomena to process information has been recognized. The purpose of this course is to introduce students to the key concepts of Quantum Information Science. It aims to establish a shared language and foundational knowledge for students to pursue advanced topics in QIS.

Course Goals: The course will introduce students to the language and formalism of Quantum Information Science and provide a foundation upon which students can take advanced courses.

Student Learning Outcomes (aka Objectives): Upon completion of the course, students will have gained the necessary mathematical background for quantum states and quantum operations. They will be fluent with the "bra-ket" notation and the analysis of quantum circuits. They will be familiar with important application areas of Quantum Information Science, such as quantum computing and quantum communication, and be able to implement important quantum protocols.

Course Outline:

- (8 Lectures) **Review of concepts from linear algebra using the notation of quantum mechanics.**
  (Includes: "bra-ket" notation, properties of vector spaces, inner product, linear operators

(Hermitian, Projectors, Unitary), outer product, eigenvectors/eigenvalues, tensor product, polar and singular value decomposition)

- (8 Lectures) **Postulates of quantum mechanics**

  (State space, evolution, general measurements, POVMs, composite systems, density operators, reduced density operators, purification)

- (2 Lectures) **Some notable consequences**

  (entanglement and Bell's inequality, no-cloning theorem)

- (2 Lectures) **Introduction to quantum communication and cryptography**

  (quantum teleportation, dense coding, BB84 quantum key distribution)

- (3 Lectures) **Quantum circuits**

  (single and two-qubit gates, controlled operations, universality, quantum simulation)

- (7 Lectures) **Quantum Algorithms** (Deutsch-Jozsa, Bernstein-Vazirani, Simon, Quantum Fourier Transform, Phase estimation, Order finding, Quantum search, Amplitude amplification)

Textbook:

The recommended textbooks for undergraduate students: "Quantum Computer Science: An Introduction" by N. David Mermin (also see here http://mermin.lassp.cornell.edu/qcomp/CS483.html)

More advanced, but highly recommended: "Quantum Computation and Quantum Information" by Michael Neilson & Isaac Chuang.

Links to other resources will be provided on the course website.

Grading:

- 30%: Problem sets

- 30%: Midterm

- 40%: Final Exam

- 0%: Voluntary final project

Problem sets and exams regularly include bonus problems, and therefore the total score can be more than 100%. Only in borderline cases, participation in class can potentially bump the grade to the next letter grade.

Graduate & undergraduate sections: Each problem set and exam will include some problems only for the students registered in 500 section of the course.

Problem sets: Expect around 10 problem sets. The lowest grade is not counted in the final score. A clean presentation of the solutions is evaluated and is part of the grading. Both Latex generated PDF or a clean scan of handwritten solutions (in one PDF file) are accepted. Discussions on the problem sets are encouraged. The final solution must be written individually, and any collaboration/discussion on the problem set needs to be acknowledged in the returned solutions. Solutions to the problem sets will be posted right after the deadline.

Final project: The final project is completely voluntary and does not contribute to the final grade. My goal is to provide an opportunity for volunteer students to gain research experience and also guidance for their presentations. I will meet regularly with the volunteers to discuss the topic and the assigned paper, and also provide guidance on presentation.

The final project consists of an oral presentation (20 minutes) to the class. A list of suggested papers will be provided, but students are encouraged to suggest the topic of their interest. The chosen topic needs to be confirmed by the instructor. The expectation is to be able to digest the basic concepts and the main questions that are answered in the paper, critically examine the assumptions and limitations, compare and contrast them to each other, and effectively present them to your classmates by connecting to the topics that have been discussed in the class.

Grade distribution: Graduate students must earn a C or higher to earn credit for the course. Percentage breakdown to grading breakdown:

Score	>100	93-100	90-93	87-90	83-87	80-83	77-80	73-77	<73
Grade	A+	A	A-	B+	B	B-	C+	C	F

COVID-19 Health and Awareness:
UNM is a mask friendly, but not a mask required, community. To be registered or employed at UNM, Students, faculty, and staff must all meet UNM's Administrative Mandate on Required COVID-19 vaccination. If you are experiencing COVID-19 symptoms, please do not come to class. If you have a positive COVID-19 test, please stay home for five days and isolate yourself from others, per the Centers for Disease Control (CDC) guidelines. If you do need to stay home, please communicate with me at mmarvian@unm.edu; I can work with you to provide alternatives for course participation and completion. UNM faculty and staff know that these are challenging times. Please let me, an advisor, or another UNM staff member know that you need support so that we can connect you to the right resources. Please be aware that UNM will publish information on websites and email about any changes to our public health status and community response.

Support:

Student Health and Counseling (SHAC) at (505) 277-3136. If you are having active respiratory symptoms (e.g., fever, cough, sore throat, etc.) AND need testing for COVID-19; OR If you recently tested positive and may need oral treatment, call SHAC.

LoboRESPECT Advocacy Center (505) 277-2911 can offer help with contacting faculty and managing challenges that impact your UNM experience.

Accommodation:
UNM is committed to providing equitable access to learning opportunities for students with documented disabilities. As your instructor, it is my objective to facilitate an inclusive classroom setting, in which students have full access and opportunity to participate. To engage in a confidential conversation about the process for requesting reasonable accommodations for this class and/or program, please contact Accessibility Resource Center at arcsrvs@unm.edu or by phone at 505-277-3506.

Support: Contact Accessibility Resource Center (https://arc.unm.edu/) at arcsrvs@unm.edu (505) 277-3506.

Credit hour statement:
This is a three credit-hour course. Class meets for two 65-minute sessions of direct instruction for fifteen weeks during the Spring 2023 semester. Please plan for a minimum of six hours of out-of-class work (or homework, study, assignment completion, and class preparation) each week.

Support: Center for Academic Program Support (CAPS). Many students have found that time management workshops can help them meet their goals (consult (CAPS) website under "services").

Title IX:
In an effort to meet obligations under Title IX, UNM faculty, Teaching Assistants, and Graduate

Assistants are considered "responsible employees." This designation requires that any report of gender discrimination which includes sexual harassment, sexual misconduct and sexual violence made to a faculty member, TA, or GA must be reported to the Title IX Coordinator at the Office of Equal Opportunity (oeo.unm.edu). For more information on the campus policy regarding sexual misconduct, see: https://policy.unm.edu/university-policies/2000/2740.html

Support: LoboRESPECT Advocacy Center and the support services listed on its website, the Women's Resource Center and the LGBTQ Resource Center all offer confidential services and reporting.

Citizenship and/or Immigration Status:
All students are welcome in this class regardless of citizenship, residency, or immigration status. Your professor will respect your privacy if you choose to disclose your status. As for all students in the class, family emergency-related absences are normally excused with reasonable notice to the professor, as noted in the attendance guidelines above. UNM as an institution has made a core commitment to the success of all our students, including members of our undocumented community. The Administration's welcome is found on our website: http://undocumented.unm.edu/.

Academic Integrity Statement:
Each student is expected to maintain the highest standards of honesty and integrity in academic and professional matters. The University reserves the right to take disciplinary action, up to and including dismissal, against any student who is found guilty of academic dishonesty or otherwise fails to meet the standards. Any student judged to have engaged in academic dishonesty in course work may receive a reduced or failing grade for the work in question and/or for the course. Academic dishonesty includes, but is not limited to, dishonesty in quizzes, tests, or assignments; claiming credit for work not done or done by others; hindering the academic work of other students; misrepresenting academic or professional qualifications within or without the University; and nondisclosure or misrepresentation in filling out applications or other University records.

Safety:
UNM offers several resources to help keep Lobos safe. LoboGuardian, https://loboguardian.unm.edu is a mobile app that increases user safety by creating a virtual safety network of friends and family. The entire UNM campus has blue light emergency phones. UNM Police Department, tel.: (505) 277-2241, offers a free escort service for safety. Lobo Alerts https://loboalerts.unm.edu is UNM's emergency text messaging system that can inform you of any occurrences that impact safety. Get Help Now at https://loborespect.unm.edu/GetStudent Health Services https://shac.unm.edu provides counseling and health services to all students.