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: EECE-210

Credit hours: 3

Office hours: Mondays 5-6pm both in-person and on zoom;
Email me for additional hours.
Zoom: https://unm.zoom.us/my/marvian
My office: ECE 235-D

Grader: Kevin Baca (back190@unm.edu)
Grader's office hour: Friday 12-1pm; PAIS lobby

Midterm 1 date (tentative): 8 October 1:30-2:45pm, in class

Midterm 2 date (tentative): 14 November, 1:30, in class.

Final exam: Tuesday, December 10, 1:30-4:30pm in the usual class (210 ECE).

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. This course aims 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:

Highly recommended: "Quantum Computation and Quantum Information" by Michael Neilson & Isaac Chuang.

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

Also going over the exercises of Introduction to Classical and Quantum Computing by T. Wong (introductory) is recommended.

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

Grading:

- 30%: Problem sets

- 40%: Midterms

- 30%: 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

Responsible Learning and Academic Honesty:
Cheating and plagiarism (academic dishonesty) are often driven by lack of time, desperation, or lack of knowledge about how to identify a source. Communicate with me and ask for help, even at the last minute, rather than risking your academic career by committing academic dishonesty. Academic dishonesty involves presenting material as your own that has been generated on a website, in a publication, by an artificial intelligence algorithm (AI), by another person, or by otherwise breaking the rules of an assignment or exam. It is a Student Code of Conduct violation that can lead to a disciplinary procedure. When you use a resource (such as an AI, article, a friend's work, or a website) in work submitted for this class, document how you used it and distinguish between your original work and the material taken from the resource.

Credit hour statement:
This is a three credit-hour course. Class meets for two 75-minute sessions of direct instruction for fifteen weeks during the Fall 2024 semester. Please plan for a minimum of six hours of out-of-class work (or homework, study, assignment completion, and class preparation) each week.

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 (https://arc.unm.edu/) 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.

Title IX:
The University of New Mexico and its faculty are committed to supporting our students and providing an environment that is free of bias, discrimination, and harassment. The University's programs and activities, including the classroom, should always provide a space of mutual respect, kindness, and support without fear of harassment, violence, or discrimination. Discrimination on the basis of sex includes discrimination on the basis of assigned sex at birth, sex characteristics, pregnancy and pregnancy related conditions, sexual orientation and gender identity. If you have encountered any form of discrimination on the basis of sex, including sexual harassment, sexual assault, stalking, domestic or dating violence, we encourage you to report this to the University.

You can access the confidential resources available on campus at the LoboRESPECT Advocacy Center (https://loborespect.unm.edu), the Women's Resource Center (https://women.unm.edu),

and the LGBTQ Resource Center (https://lgbtqrc.unm.edu). If you speak with an instructor (including a TA or a GA) regarding an incident connected to discrimination on the basis of sex, they must notify UNM's Title IX Coordinator that you shared an experience relating to Title IX, even if you ask the instructor not to disclose it. The Title IX Coordinator is available to assist you in understanding your options and in connecting you with all possible resources on and off campus. For more information on the campus policy regarding sexual misconduct and reporting, please see https://policy.unm.edu/university-policies/2000/2740.html and CEEO's website.

If you are pregnant or experiencing a pregnancy-related condition, you may contact UNM's Office of Compliance, Ethics, and Equal Opportunity at ceeo@unm.edu. The CEEO staff will provide you with access to available resources and supportive measures and assist you in understanding your rights.

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/.

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.

Respectful Conduct Expectations: I am committed to building with you a positive classroom environment in which everyone can learn. I reserve the right to intervene and enforce standards of respectful behavior when classroom conduct is inconsistent with University expectations [and/or classroom community agreements]. Interventions and enforcement may include but are not limited to required meetings to discuss classroom expectations, written notification of expectations, and/or removal from a class meeting. Removal from a class meeting will result in an unexcused absence. [Insert number] or more unexcused absences may result in permanent removal and a drop from the course (see attendance policy). The University of New Mexico ensures freedom of academic inquiry, free expression and open debate, and a respectful campus through adherence to the following policies: D75: Classroom Conduct, Student Code of Conduct, University Policy 2240 – Respectful Campus, University Policy 2210 – Campus Violence.