ILLINOIS COMPUTER SCIENCE | ONLINE MCS

CS 598: Quantum Computing - Foundations and Programming

TERM	Fall 2026
DELIVERY	Online MCS through Coursera
INSTRUCTOR	Dakshita Khurana
EMAIL	dakshita@illinois.edu
OFFICE HOURS	Tuesdays, 2:00-3:00 p.m. Central Time, beginning September 1
TEACHING ASSISTANT	Kabir Tomer, ktomer2@illinois.edu

Course description

This course aims to introduce the principles of quantum computing, laying a solid foundation for further advanced courses or research in quantum information.

Topics include the basic concepts and axioms of quantum information; qubits and entanglement; quantum gates and measurement; quantum communication protocols such as teleportation and superdense coding; and quantum algorithms including Simon's algorithm, the quantum Fourier transform, phase estimation, Shor's factoring algorithm, Grover search, and amplitude amplification. Advanced topics may include quantum complexity, cryptography, and error correction.

The course takes a theoretical computer science perspective on quantum computing. No background in quantum physics is required.

Prerequisites

Students must be comfortable with:

- Abstract linear algebra, including complex vector spaces, inner products, matrices, eigenvectors, unitary transformations, and tensor products
- Probability, including conditional probability, random variables, expectation, and normalization
- Mathematical reasoning and proof
- Basic programming concepts

Familiarity with algorithms and asymptotic analysis is strongly recommended. Prior experience with Python or Qiskit is helpful but not required.

The Start Here module includes an ungraded prerequisite self-check and refresher resources. These resources are intended for review rather than as substitutes for the prerequisites.

Communication and support

- **Announcements:** Coursera is the official source for course announcements and deadline changes.
- **Course questions:** Use Piazza so other students can benefit from the discussion.
- **Private matters:** Send a private Piazza message or contact the instructor at dakshita@illinois.edu.

- **Office hours:** Tuesdays, 2:00-3:00 p.m. Central Time, beginning September 1
- **Platform problems:** Use Coursera's Learner Help resources.
- **Course-specific notebook problems:** Post privately on Piazza when the question includes code or assignment details.

Students should not post assignment solutions, code, grades, autograder details, or personal information publicly on Piazza.

The instructional team will ordinarily respond to course questions within two business days. Responses may take longer on weekends and University holidays.

Learning objectives

By the end of the course, students will be able to:

1. Represent quantum states and operations using bra-ket notation, complex vector spaces, tensor products, and unitary matrices.
2. Compute measurement outcome probabilities and normalized post-measurement states for full and partial projective measurements.
3. Distinguish global phase from relative phase and explain how interference affects quantum measurement outcomes.
4. Identify entangled states and analyze EPR and CHSH correlations produced by local measurements.
5. Derive the correctness and resource requirements of quantum teleportation and superdense coding.
6. Prove and apply limitations on quantum information, including the no-cloning theorem and bounds on extracting classical information.
7. Construct and analyze reversible circuits, oracle constructions, ancilla qubits, uncomputation, and universal gate sets.
8. Analyze Deutsch-Jozsa, Simon's algorithm, Grover search, the quantum Fourier transform, phase estimation, period finding, and Shor's algorithm.
9. Use density matrices, reduced states, quantum channels, and elementary error-correcting codes to analyze mixed states and noise.
10. Evaluate claims of quantum advantage using appropriate resource measures and complexity models, distinguishing asymptotic speedups from present-day hardware performance.
11. Implement and test quantum circuits and algorithms in Qiskit using simulation; evaluate their correctness, resource use, and robustness.

Course organization

This course follows a flipped-classroom format. New asynchronous course material will be released each Monday. The course will use a rolling two-week window: the current module and the following module will ordinarily be available, allowing students to adjust their pace based on their backgrounds and schedules.

Students are expected to complete the current week's Core module, including its assigned videos, readings, and short checks, before the Quantum Studio on Thursday. The Studio will assume familiarity with this material and will focus on applying, discussing, and extending it rather than presenting it for the first time.

Live Online Meetings

All live online meetings use the course Zoom room.

The first class meeting will be held on Tuesday, August 25, from 2:00-3:30 p.m. Central Time. Beginning Tuesday, September 1, the instructor will hold optional office hours on Tuesdays from 2:00-3:00 p.m. Central Time.

A weekly Quantum Studio will meet on Thursdays from 2:00-3:00 p.m. Central Time. Studios will emphasize guided problem solving, discussion, clarification of difficult concepts, and occasional previews or extensions of the asynchronous material. They will not repeat the recorded lectures.

For students enrolled in QC1, participation in the weekly Quantum Studio is expected as part of the scheduled course experience, although attendance is not separately graded. Students who cannot attend a particular meeting should complete the posted asynchronous Studio activity.

For students enrolled in QC2, the Quantum Studio is available but is not required.

Studio main-room activities will ordinarily be recorded and posted. Breakout-room conversations will not be recorded. A worksheet, solution or recap, and an equivalent asynchronous activity will be provided so that essential course content is accessible to students who cannot attend synchronously.

Individual welcome conversations

During the first week of the course, students are invited to an informal, individual 15-minute Zoom conversation with the instructor.

Please use Calendly to book one of the available Zoom slots on Wednesday, August 26, or Friday, August 28.

The purpose of the conversation is to learn about each student's background, interests, goals, and initial questions. No preparation is needed. The conversation is optional, ungraded, and will not be recorded. Students unable to meet during the listed times may contact the instructor to arrange another time.

Course platforms

- **Coursera:** Lectures, readings, assignments, grades, announcements, and official deadlines
- **Coursera Resources:** The course syllabus, policies, and course-wide reference materials
- **Piazza:** Course questions, discussion, clarifications, private communication, and peer interaction
- **Coursera notebooks:** Qiskit programming activities and programming-assignment submissions
- **Office hours:** Optional live questions and additional explanation on Tuesdays from 2:00-3:00 p.m. Central Time, beginning September 1
- **Quantum Studio:** Weekly guided problem solving and discussion on Thursdays from 2:00-3:00 p.m. Central Time

Students should check Coursera announcements and Piazza regularly.

Start Here

Students should complete the Start Here module before beginning the first content module. It contains:

1. How This Course Works
2. Prerequisite Self-Check
3. Linear Algebra Refresher
4. Probability Refresher
5. Instructions for joining the course Piazza
6. Course Syllabus

The prerequisite self-check is ungraded.

Materials and software

There is no required textbook. All required course materials will be provided through Coursera.

The following are recommended references. They are not required purchases or readings unless a particular section is assigned in a module:

- Michael A. Nielsen and Isaac L. Chuang, *Quantum Computation and Quantum Information*
- Scott Aaronson, *Introduction to Quantum Information Science*
- Ronald de Wolf, *Quantum Computing: Lecture Notes*
- Ryan O'Donnell and John Wright, *Quantum Computation* lecture notes

Programming work uses Python, Jupyter notebooks, and Qiskit in a managed course environment. Assignments use simulated quantum computers; physical quantum hardware and a separate IBM Quantum account are not required.

Written problem sets

The course includes three written problem sets. Each problem set is worth 10% of the course grade.

1. **Quantum States, Measurement, and Entanglement**
   Qubits, measurement, interference, tensor products, entanglement, EPR and CHSH correlations, no-cloning, and quantum communication protocols.
2. **Quantum Circuits and Hidden Structure**
   Reversible computation, oracle constructions, ancillas, uncomputation, phase kickback, Deutsch-Jozsa, and the foundations of Simon's algorithm.
3. **Quantum Algorithms**
   The quantum Fourier transform, phase estimation, period finding, Shor's algorithm, Grover search, amplitude amplification, and limits of quantum search.

Problem sets may contain calculations, circuit analysis, mathematical derivations, and short proofs.

Programming assignments

The course includes three substantial autograded programming assignments. Each assignment is worth 10% of the course grade.

1. **Reversible Oracles and Hidden Structure**
   Construct reversible oracles and implement Deutsch-Jozsa and Simon's algorithm, including classical post-processing.
2. **Fourier Methods and Period Finding**
   Implement the quantum Fourier transform, phase estimation, and small instances of order or period finding.
3. **Search, Noise, and Error Correction**
   Implement Grover search, study its behavior under noise, and construct elementary error-detection or error-correction circuits.

Students receive starter notebooks and visible tests. Hidden tests may assess correctness on additional inputs, output format, circuit resources, reproducibility, and robustness.

The assignments will be autograded. Grading will not depend on access to external quantum hardware.

Assessment and grading

Assessment	Weight
Three written problem sets	30%
Three autograded programming assignments	30%
Cumulative final examination	40%

Assessment	Weight
Total	**100%**

The prerequisite self-check and practice activities are ungraded.

There is no midterm examination.

Assessment dates

Assessment	Deadline
Written Problem Set 1	September 27
Written Problem Set 2	October 11
Programming Assignment 1	October 25
Programming Assignment 2	November 8
Written Problem Set 3	November 15
Programming Assignment 3	December 6
Final examination	University final-examination period

No graded work is due during Fall Break.

The cumulative final examination is worth 40% of the course grade. Its format, permitted materials, and exact date or availability window will be announced after the Fall 2026 examination schedule is confirmed. The University currently plans to publish the schedule on October 14.

Fall 2026 teaching schedule

The schedule follows the current Fall 2026 UIUC academic calendar. University dates remain subject to revision.

Week	Dates	Module and topics
Start Here	Before Aug. 25	Orientation, prerequisite self-check, mathematics refreshers, and Piazza
1	Aug. 25 and 27	**Quantum Information and Qubits:** motivation, qubits, amplitudes, bra-ket notation, normalization, and the Born rule
2	Sept. 1 and 3	**Measurement, Quantum Operations, and Interference:** projective measurement, post-measurement states, unitary operations, gates, phase, and interference
3	Sept. 8 and 10	**Multi-Qubit Systems and Entanglement:** tensor products, basis ordering, controlled gates, Bell states, product states, and entangled states
4	Sept. 15 and 17	**Partial Measurement, EPR Correlations, and Bell's Theorem:** conditional states, EPR experiments, CHSH correlations, and Bell inequalities
5	Sept. 22 and 24	**Limits of Quantum Information and Communication Protocols:** no-cloning, state discrimination, superdense coding, and teleportation
6	Sept. 29 and Oct. 1	**Information Limits, Circuit Models, and Reversible Computation:** Holevo's theorem, circuit models, reversible oracles, ancillas, uncomputation, and universal gates

Week	Dates	Module and topics
7	Oct. 6 and 8	**Phase Kickback, Deutsch-Jozsa, and Simon's Algorithm:** phase kickback, promise problems, quantum oracles, and the first part of Simon's algorithm
8	Oct. 13 and 15	**Simon's Algorithm:** classical post-processing, success probability, correctness, and resource analysis
9	Oct. 20 and 22	**The Quantum Fourier Transform:** Fourier basis states, controlled rotations, the QFT circuit, inverse QFT, and an introduction to phase estimation
10	Oct. 27 and 29	**Phase Estimation and Period Finding:** accuracy, success probability, period finding, order finding, and the connection to factoring
11	Nov. 3 and 5	**RSA, Shor's Algorithm, and Grover Search:** factoring by order finding and the geometric interpretation of quantum search
12	Nov. 10 and 12	**Amplitude Amplification and Limits of Quantum Search:** optimal iteration counts, multiple marked items, amplitude amplification, and lower bounds
13	Nov. 17 and 19	**Mixed States, Quantum Channels, Noise, and Tomography:** density operators, reduced states, partial trace, channels, noise models, and introductory tomography
14	Nov. 24 and 26	**Fall Break:** no new material or required course activity
15	Dec. 1 and 3	**Quantum Error Correction and Quantum Cryptography:** bit and phase errors, syndrome measurement, elementary codes, BB84, and security assumptions
16	Dec. 8	**Quantum Complexity, Advantage, Local Hamiltonians, and Final Review:** BQP, QMA, resource measures, current hardware limitations, and final-exam preparation
Reading Day	Dec. 10	No class or mandatory course activity
Final period	Dec. 11-17	Cumulative final examination; exact arrangements to be announced

Workload

Students should plan for approximately 10-12 hours of course work per week. Workload may be higher during programming assignments and final-exam preparation.

Students requiring substantial review of linear algebra, probability, or programming should budget additional time early in the semester.

Collaboration policy

Discussion of course concepts and high-level approaches is encouraged. Unless an assignment explicitly states otherwise, all submitted mathematical work and code must be produced independently.

Students may not exchange complete solutions, notebooks, code, hidden-test information, or examination content. External sources and permitted assistance must be acknowledged as directed in the assignment.

Students must write the names of all collaborators on each assignment submission. If there were no collaborators, students should write "No collaborators."

AI policy

AI tools may be used as study aids and for limited programming support, including:

- Asking for explanations of course concepts
- Reviewing Python or Qiskit syntax

- Interpreting error messages
- Suggesting tests for code the student has written

Students may not use an AI system to generate or substantially rewrite an assignment solution, mathematical proof, or required program. Students may not use AI tools during the final examination.

Assignment-related AI use must be disclosed in the designated notebook cell or submission statement. Students remain responsible for understanding and verifying everything they submit.

Assignment-specific instructions take precedence over this general policy.

Late-work policy

Written problem sets and programming assignments include an automatic 24-hour grace window. No email or extension request is needed to use this window.

After the grace window closes, submissions will not ordinarily be accepted except in cases involving approved accommodations, documented emergencies, religious observances, or University-recognized activities.

The grace window does not apply to the final examination. Students anticipating an examination conflict should contact the instructor as early as possible.

Academic integrity

Students must follow the University of Illinois Student Code and the University's academic-integrity requirements.

Unauthorized collaboration, copied code, undisclosed use of external solutions, fabricated results, sharing examination material, or attempts to infer hidden autograder tests may constitute academic misconduct.

When uncertain about whether a resource or form of assistance is permitted, students should ask before submitting their work.

Accessibility and accommodations

Students seeking disability-related accommodations should contact Disability Resources and Educational Services and provide the instructional team with the appropriate accommodation documentation.

Students are encouraged to begin this process early so arrangements can be implemented promptly and privately. Course videos will include captions or transcripts, and course documents will be prepared in accessible formats wherever practicable.

Statement on Anti-Racism and Inclusivity

The intent of this section is to raise student and instructor awareness of the ongoing threat of bias and racism and of the need to take personal responsibility in creating an inclusive learning environment.

The Grainger College of Engineering is committed to the creation of an anti-racist, inclusive community that welcomes diversity along a number of dimensions, including, but not limited to, race, ethnicity and national origins, gender and gender identity, sexuality, disability status, class, age, or religious beliefs. The College recognizes that we are learning together in the midst of the Black Lives Matter movement, that Black, Hispanic, and Indigenous voices and contributions have largely either been excluded from, or not recognized in, science and engineering, and that both overt racism and micro-aggressions threaten the well-being of our students and our university community.

The effectiveness of this course is dependent upon each of us to create a safe and encouraging learning environment that allows for the open exchange of ideas while also ensuring equitable opportunities and respect for all of us. Everyone is expected to help establish and maintain an environment where students, staff, and faculty can contribute without fear of personal ridicule, or intolerant or offensive language. If you witness or experience racism, discrimination, micro-aggressions, or other offensive behavior, you are encouraged to bring this to the attention of the course director if you feel comfortable. You can also report these behaviors to the Bias Assessment and Response Team (BART). Based on your report, BART members will follow up and reach out to students to make sure they have the support they need to be healthy and safe. If the reported behavior also violates university policy, staff in the Office for Student Conflict Resolution may respond as well and will take appropriate action.

Statement on CS CARES and CS Values and Code of Conduct

All members of the Illinois Computer Science department - faculty, staff, and students - are expected to adhere to the CS Values and Code of Conduct. The CS CARES Committee is available to serve as a resource to help people who are concerned about or experience a potential violation of the Code. If you experience such issues, please contact the CS CARES Committee. The Instructors of this course are also available for issues related to this class.

Statement on Mental Health

Diminished mental health, including significant stress, mood changes, excessive worry, substance/alcohol abuse, or problems with eating and/or sleeping can interfere with optimal academic performance, social development, and emotional well-being. The University of Illinois offers a variety of confidential services including individual and group counseling, crisis intervention, psychiatric services, and specialized screenings at no additional cost. If you or someone you know experiences any of the above mental health concerns, it is strongly encouraged to contact or visit any of the University's resources provided below. Getting help is a smart and courageous thing to do - for yourself and for those who care about you.

Counseling Center: 217-333-3704, 610 East John Street Champaign, IL 61820

McKinley Health Center:217-333-2700, 1109 South Lincoln Avenue, Urbana, Illinois 61801

University wellness center: https://wellness.illinois.edu

Absences and religious observances

Students enrolled in QC1 are expected to participate in the weekly Quantum Studio or complete the posted asynchronous Studio activity when they cannot attend. For students enrolled in QC2, synchronous Studio participation is available but not required. Attendance is not separately graded. All students remain responsible for completing course work by the published deadlines.

Accommodations for religious observances, disability-related needs, and qualifying University activities will be handled in accordance with the Student Code absence provisions.

Additional safety and support resources

Information about confidential support and University reporting obligations concerning sexual misconduct is available through We Care. Emergency guidance is available in the University’s Emergency Response Guide.

For imminent danger, call 911. Students in the United States experiencing a mental-health crisis may call or text 988.

Course changes

The instructional team may make reasonable adjustments to the schedule, assessments, or assigned materials. Material changes will be communicated through a Coursera announcement.