Universidad de Alcalá

TEACHING GUIDE

Introduction to Quantum Mechanics and Quantum Computing

Degree in
Computer Science Engineering (GII)
Computer Engineering (GIC)
Information System Engineering (GISI)

Universidad de Alcalá

Academic Year 2026/2027

4th Year - 1st Semester (GII+GIC+GISI)

Approved by the EPS School Board on June 15th, 2026

TEACHING GUIDE

Course Name:	**Introduction to Quantum Mechanics and Quantum Computing**
Code:	**781011 (GII+GIC+GISI)**
Degree in:	**Computer Science Engineering (GII)** **Computer Engineering (GIC)** **Information System Engineering (GISI)**
Department and area:	**Automática** **Arquitectura y Tecnología de Computadores.**
Type:	**Optional (Generic) (GII+GIC+GISI)**
ECTS Credits:	**6.0**
Year and semester:	**4th Year - 1st Semester (GII+GIC+GISI)**
Teachers:	Álvaro Perales Eceiza
Tutoring schedule:	To be determined at the beginning of the term.
Language:	English

1. COURSE SUMMARY

This course aims to provide an introduction to the basic concepts and tools of both Quantum Mechanics (QM) and Quantum Computation (QC) for computer science students.

The approach to QM will be historical first, explaining the foundations (Schrödinger Equation, Hilbert Spaces, Superposition, Dirac-von Neumann postulates), to subsequently point out and delve into the less understood and highly debated aspects: the measurement problem, interpretations of QM, the EPR paradox, Bell's inequalities, etc.The approach to QC will be oriented toward practical laboratory work with Qiskit, a widely used algorithm and circuit development platform where programs can be executed on real IBM quantum computers in the cloud, while providing a realistic view of what is currently being done in the industry.

The general purpose is to provide a global vision of QM theory, with its conceptual foundations and its challenges, and a solid practical basis to understand, design, and execute quantum algorithms that can serve as a foundation for students who decide to continue in the field.

2. SKILLS

Basic, Generic and Cross Curricular Skills.

This course contributes to acquire the following basic, generic and cross curricular skills:

en_CB1 - That students have demonstrated to possess and understand knowledge in an area of study that is based on general secondary education, and is usually found at a level that, although supported by advanced textbooks, also includes some aspects that involve knowledge from the forefront of their field of study.

en_CB2 - That the students know how to apply their knowledge to their work or vocation in a professional manner and possess the competencies that are usually demonstrated through the elaboration and defense of arguments and the resolution of problems within their area of study.

en_CB3 - That students have the ability to gather and interpret relevant data (usually within their area of study) to make judgments that include a reflection on relevant social, scientific or ethical issues.

en_CB4 - That students can transmit information, ideas, problems and solutions to both a specialized and non-specialized public.

en_CB5 - That the students have developed those learning skills necessary to undertake further studies with a high degree of autonomy.

en_TRU1 - Capacity of analysis and synthesis.

en_TRU2 - Oral and written competencies.

en_TRU3 - Ability to manage information.

en_TRU4 - Autonomous learning skills.

en_TRU5 - Team work.

Learning outcomes

After succeeding in this subject the students will be able to:

- **LO1**. To understand the historical development of Quantum Mechanics, its conceptual and mathematical foundations, and the Dirac-von Neumann postulates.
- **LO2.** To understand the foundational debates and interpretations of Quantum Mechanics, including the measurement problem, non-locality, the EPR paradox, and Bell's inequalities.
- **LO3.** To operate with single and multi-qubit states using Bra-Ket notation, state vectors, the Bloch sphere, unitary matrices, and tensor products.
- **LO4.** To use quantum software development platforms, circuit diagrams, and cloud-based quantum hardware, specifically within the Qiskit ecosystem.
- **LO5.** To program, simulate, and execute foundational quantum algorithms in Qiskit, and to understand the mechanism of advanced algorithms like Shor and Grover.
- **LO6.** To evaluate the physical limitations of current NISQ hardware (noise, decoherence), the current practical applications of quantum computing in the industry, and the future perspectives.

3. CONTENTS

Contents Blocks	Total number of hours
1. Introduction. Course motivation 1.1 What is Quantum Mechanics? The weird microscopic world. 1.2 Physics meets Computer Science: What makes QM fundamentally different and computationally powerful? 1.3 QC in Action: Present-day applications and future possibilities.	• 4 theory hours
2. Quantum Mechanics (QM) 2.1 Historical Introduction: From Planck to Dirac (Planck, Einstein, Bohr, de Broglie, Pauli, Heisenberg, Schrödinger, Born, Dirac). 2.2 Mathematical Foundations: Wave function, Hilbert spaces. Schrödinger Equation. The Dirac-von Neumann postulates 2.3 Simple solutions: Solving the Schrödinger Equation elementary potentials 2.4 Foundations of Quantum Information: Superposition, composite systems, and Entanglement. 2.5 The Frontiers of Reality: Schrödinger's Cat and the Measurement Problem. 2.6 Local Realism? The EPR Paradox, hidden variables, and Bell's inequalities. 2.7 Interpretations of QM (Copenhagen, Many-Worlds, de Broglie-Bohm, Objective collapse Theories) 2.8 What does all this mean for our understanding of reality? Challenging classical world through non-locality, determinism vs. randomness, and the limits of understanding.	• 16 theory hours

3. Quantum Computing (QC) 3.1 Bit vs. Qubit, Bra-Ket notation, state vectors, and the Bloch Sphere representation. 3.2 Single-Qubit Operations: Unitary matrices, Phase gates, the Pauli Group and the Hadamard gates. 3.3 Multi-Qubit Systems: Tensor products, entanglement generation, and Controlled Gates (C-NOT, C-U, SWAP). 3.4 Quantum Circuits and Frameworks: Circuit diagrams, measurement operators, and practical introduction to the Qiskit Platform. 3.5 Foundational Quantum Algorithms: Deutsch, Deutsch-Jozsa, and Simon algorithms (Quantum parallelism and interference). 3.6 Advanced Algorithms: Conceptual overview of Shor's Factoring Algorithm and Grover's Search Algorithm. 3.7 Contemporary Hardware & Constraints: Quantum Decoherence, Noise, the NISQ (Noisy Intermediate-Scale Quantum) era, and principles of Quantum Error Correction. 3.8 Real-World Applications: Quantum simulation (quantum chemistry, materials science), combinatorial optimization in logistics, quantum finance, and introduction to Quantum Machine Learning (QML). 3.9 Critical Perspectives: Physical bottlenecks, scalability challenges, and hype vs. reality in the current quantum era.	• 8 theory hours • 30 lab hours

4. TEACHING - LEARNING METHODOLOGIES. FORMATIVE ACTIVITIES.

4.1. Credits Distribution

Number of on-site hours:	58 hours (56 hours on-site +2 exams hours)
Number of hours of student work:	92
Total hours	150

4.2. Methodological strategies, teaching materials and resources

The course balances theoretical foundations with practical experimentation through four main components:

- **Large Group Sessions (Theory):** Lectures to introduce the principles of QM and QC. The approach evolves from historical debates to formal mathematical models, linking concepts with other computer science subjects to keep students engaged.
- **Small Group Sessions (Problem Solving):** Classes focused on analytical problem solving (quantum states, unitary matrices, and tensor products) and collaborative discussions regarding quantum mechanics interpretations and algorithms.
- **Laboratory Sessions (Qiskit Practice):** Group work to design, simulate, and execute quantum circuits using the Qiskit framework. Students use local simulators and cloud-based IBM quantum hardware to analyze the constraints of NISQ systems.
- **Independent Work:** Autonomous study including reviewing lecture notes, solving problem sets, completing pre-lab exercises, and attending individual or group tutorials.

Teaching Materials and Resources

- **Course Repository:** Slide decks, problem sheets, reading assignments, and code templates.
- **Software Ecosystem:** IBM Qiskit SDK.
- **Hardware Access:** IBM Quantum Services cloud platform to access real quantum processors.

5. ASSESSMENT: procedures, evaluation and grading criteria

Preferably, students will be offered a continuous assessment model that has characteristics of formative assessment in a way that serves as feedback in the teaching-learning process.

5.1. PROCEDURES

The evaluation must be inspired by the criteria of continuous evaluation (Learning Assesment Guidelines, LAG, art 3). However, in compliance with the regulations of the University of Alcalá, an alternative process of final evaluation is made available to the student in accordance with the Learning Assesment Guidelines as indicated in Article 10, students will have a period of fifteen days from the start of the course to request in writing to the Director of the Polytechnic School their intention to take the non-continuous evaluation model adducing the reasons that they deem convenient. The evaluation of the learning process of all students who do not apply for it or are denied it will be done, by default, according to the continuous assessment model. The student has two calls to pass the subject, one ordinary and one extraordinary.

Ordinary Call

Continouos Assessment:

It will consist of completion and delivery of learning and assessment activities distributed throughout the semester.

The theory grade will be set based on the performance in two exams during the course.

The lab grade will be set based on the completion, submission and defence of the proposed practices. The realisation in the lab of such practices is compulsory and therefore there is no final lab exam. The only way to pass the lab (and therefore the subject) is finishing properly the practices on schedule in the lab.

Students who undergo continuous evaluation and failed will not be qualified for the final evaluation of the ordinary call

Assessment through final exam:

Students who obtain permission from the Director of the Centre to qualify for the final evaluation will be evaluated by a single theory exam consisting of theoretical questions and exercises similar to those carried out during the course and will account for the total theory grade.

It is essential to overcome mandatory practices carried out during the semester to pass the course. Therefore, the students who choose the final evaluation should contact the coordinator of the subject during the first two weeks of the course to set evaluating sessions during the first quarter.

Extraordinary Call

The procedure will be the same as that described for the assessment by means of a final exam in the ordinary call.

5.2. EVALUATION

EVALUATION CRITERIA

The assessment criteria measure the level in which the competences have been acquired by the student. For that purpose, the following are defined:

- **EC1.** Ability to explain the historical evolution of quantum physics, its main conceptual debates, and the fundamental postulates of the theory.
- **EC2.** Ability to solve problems involving single and multi-qubit states, unitary operations, and tensor products using standard mathematical notation.
- **EC3.** Capacity to understand quantum non-locality, the measurement problem, and the implications of Bell's inequalities.
- **EC4.** Ability to configure and use quantum software development platforms, circuit diagrams, and cloud hardware interfaces.
- **EC5.** Ability to program, simulate, and deploy foundational quantum algorithms within the Qiskit platform.
- **EC6.** Capacity to critically evaluate the architectural constraints of NISQ hardware (noise, decoherence) and identify real-world industry applications.

GRADING TOOLS

The work of the student is graded in terms of the assessment criteria above, through the following tools:

1. Ordinary call
    a. Continuous assessment, with two theory exams (**PEIT1, PEIT2**) and one lab grade calculated as average of all laboratory practical assignments (**PEIL**)
    b. Final assessment (**PEFT** and **PEFL**)
2. Extraordinary call. Final assessment for both theory (**EC_PEFT**) and lab (**EC_PEFL**)

NOTE: Both PEFL and EC_PEFL require the completion, submission, and on-site defense of ALL laboratory practical assignments. To this end, students following the non-continuous or extraordinary evaluation models must contact the course coordinator to schedule their presentation and defense

sessions.

GRADING CRITERIA

In the ordinary call-continuous assessment the relationship between the competences, learning outcomes, criteria and evaluation instruments is as follows.

Skill	Learning Outcomes	Evaluation criteria	Grading Tool	Contribution to the final mark
en_CB1, en_CB3, en_CB4, en_TRU1, en_TRU3	EC1, EC3, EC6	EC1, EC3, EC6	PEIT1	25%
en_CB2, en_CB4, en_TRU3, en_TRU5	LO3, LO5	EC2, EC5	PEIT2	25%
en_CB2, en_CB3, en_CB5, en_TRU1, en_TRU2, en_TRU4, en_TRU5	LO3, LO4, LO5, LO6	EC2, EC4, EC5, EC6	PEIL	50%

In the ordinary call-final evaluation, the relationship between the competences, learning outcomes, criteria and evaluation instruments is as follows.

Skill	Learning Outcomes	Evaluation criteria	Grading Tool	Contribution to the final mark
en_CB1, en_CB2, en_CB3, en_CB4, en_TRU1, en_TRU3, en_TRU5	LO1, LO2, LO3, LO5, LO6	EC1, EC2, EC3, EC5, EC6	PEFT	50%
en_CB2, en_CB3, en_CB5, en_TRU1, en_TRU2, en_TRU4, en_TRU5	LO3, LO4, LO5, LO6	EC2, EC4, EC5, EC6	PEFL	50%

Extraordinary call

The extraordinary call maintains the same weights as the final assessment. Students who passed either the theoretical or the laboratory component during the ordinary call can choose to preserve that grade. In that case they will only need to take the failed part (EC_PEFT or EC_PEFL).

The teaching-learning methodology and the assessment process will be adapted as needed, in accordance with the guidelines of the Diversity Support Unit, to implement curricular adaptations for students with specific needs.

6. BIBLIOGRAPHY

6.1. Basic Bibliography

- *Quantum Computation and Quantum Information.* M. Nielsen & I. Chuang (10th anniversary ed.2010). Cambridge University Press.
- *Dancing with Qubits: From qubits to algorithms, embark on the quantum computing journey shaping our future*. R. Sutor (2nd ed. 2024). Packt Publishing.
- *An Introduction to Quantum Computing*. P. Kaye, R. Laflamme & M. Mosca (2007). Oxford University Press.
- *Quantum Computing for Computer Scientists*. N. S. Yanofsky & M. A. Mannucci (2008). Cambridge University Press.
- *Quantum Computing: An Applied Approach.* J. D. Hidary (2nd ed. 2021). Springer.
- *Learn Quantum Computing.* IBM Quantum Platform. https://quantum.cloud.ibm.com/learning/

6.2. Additional Bibliography

- *What Is Real? The Unfinished Quest for the Meaning of Quantum Physics* A. Becker (2018). Basic Books.
- *Quantum: Einstein, Bohr, and the Great Debate About the Nature of Reality.* M. Kumar (2008). Icon Books.

Disclosure Note

During the evaluation tests, the guidelines set out in the Regulations establishing the Rules of Coexistence of the University of Alcalá must be followed, as well as the possible implications of the irregularities committed during said tests, including the consequences for committing academic fraud according to the Regulation of Disciplinary Regime of the Students of the University of Alcalá.