# SYLLABUS

## 1. Data about the program of study

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|---|---|
| 1.1 Institution | The Technical University of Cluj-Napoca |
| 1.2 Faculty | Faculty of Automation and Computer Science |
| 1.3 Department | Computer Science |
| 1.4 Field of study | Computer Science and Information Technology |
| 1.5 Cycle of study | Masters |
| 1.6 Program of study / Qualification | Artificial Intelligence and Vision / Masters |
| 1.7 Form of education | Full time |

## 2. Data about the subject

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|---|---|---|---|---|---|---|
| 2.1 Subject name | ***Introduction in Quantum Machine Learning*** | | | | Subject code | **5** |
| 2.2 Course responsible / lecturer | Dr. fiz. Zârbo Liviu - Liviu.Zarbo@itim-cj.ro | | | | | |
| 2.3 Teachers in charge of seminars / Laboratory / project | Dr. fiz. Zârbo Liviu - Liviu.Zarbo@itim-cj.ro | | | | | |
| 2.4 Year of study | I | 2.5 Semester | 1 | 2.6 Type of assessment (E - exam, C - colloquium, V – verification) | | C |
| 2.7 Subject category | Formative category: DF – fundamental, DS – speciality, DC – complementary | | | | | DS |
| | Optionality: DOB – mandatory, DOP – optional (alternative), DFA – optional (free choice) | | | | | DOB |

## 3. Estimated total time

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|---|---|---|---|---|---|---|---|---|---|---|
| 3.1 Number of hours per week | 2 | of which: | Course | 1 | Seminars | 1 | Laboratory | - | Project | - |
| 3.2 Number of hours per semester | 28 | of which: | Course | 14 | Seminars | 14 | Laboratory | - | Project | - |

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| 3.3 Individual study: | |
| (a) Manual, lecture material and notes, bibliography | 20 |
| (b) Supplementary study in the library, online and in the field | 20 |
| (c) Preparation for seminars/laboratory works, homework, reports, portfolios, essays | 18 |
| (d) Tutoring | - |
| (e) Exams and tests | 4 |
| (f) Other activities: | - |

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| 3.4 Total hours of individual study (suma (3.3(a)...3.3(f))) | 72 |
| 3.5 Total hours per semester (3.2+3.4) | 100 |
| 3.6 Number of credit points | 4 |

## 4. Pre-requisites (where appropriate)

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| 4.1 Curriculum | Linear Algebra<br>Mathematical Analysis<br>Physics<br>Programming |
| 4.2 Competence | |

## 5. Requirements (where appropriate)

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| 5.1. For the course | - |
| 5.2. For the applications | - |

**6. Specific competence**

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| 6.1 Professional competences | • Basic knowledge of linear algebra and calculus, first year undergraduate student level<br>• Basic programming knowledge, first year undergraduate student level |
| 6.2 Cross competences | N/A |

**7. Expected Learning Outcomes**

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| Knowledge | Qubits, quantum circuits, basic quantum algorithms, quantum machine learning algorithms |
| Skills | Implementing a quantum algorithm on a quantum platform (e.g. Uranium);<br>Being able to utilize frameworks (e.g. Qiskit) for implementing quantum algorithms. |
| Responsibilities and autonomy | |

**8. Discipline objective (as results from the *key competences gained*)**

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| 8.1 General objective | Developing general knowledge relevant to applications in the field of quantum computation and quantum machine learning |
| 8.2 Specific objectives | 1. Assimilating the basics of quantum computation: qubits, quantum gates, quantum circuits, quantum algorithms<br>2. Developing the basic skills for developing quantum algorithms<br>3. Understanding the basics of quantum machile learning. |

**9. Contents**

| **9.1 Lectures** | Hours | Teaching methods | Notes |
|---|---|---|---|
| 1. Introductory notions.<br>• From classical to quantum computing<br>• The dual behavior of the quantum objects<br>• Tunneling<br>• Double slit experiment | 2 | Blackboard, video-lectures, discussions of examples, problem solving. | |
| 2. Quantum states<br>• Notations<br>• Probabilities<br>• Matrix and vector representation of quantum states<br>• Qubits<br>• Pure states and mixed states | 2 | | |
| 3. Observables and quantum measurement 1<br>• Observables and operators<br>• The Heisenberg principle<br>• Projective measurements<br>• The Stern-Gerlach experiment | 2 | | |

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|---|---|---|---|
| 4. Observables and quantum measurement 2<br>• Quantum state vectors.<br>• Observables and operators, the density matrix.<br>• Probabilities and expectation values.<br>• Partial measurements | 2 | | |
| 5. Qubits<br>• The two-level system and real life examples<br>• Quantum gates<br>• Superpositions and entanglement of qubits<br>• The Bloch sphere. | 2 | | |
| 6. Quantum measurement and applications 1.<br>• The no-cloning theorem<br>• Quantum teleportation<br>• Quantum sensing<br>• Quantum tomography | 2 | | |
| 7. Quantum measurement and applications 2.<br>• Quantum random number generation<br>• Quantum communication protocols (BB84).<br>• Quantum cryptography notions<br>• Quantum communication networks. | 2 | | |
| 8. Quantum circuits and algorithms<br>• Quantum circuits<br>• Density matrices, noise<br>• Entanglement<br>• Computational complexity. | 2 | | |
| 9. Quantum algorithms 1.<br>• Deutsch-Josza algorithm.<br>• Grover algorithm | 2 | | |
| 10. Quantum algorithms 2.<br>• Quantum Fourier transform<br>• RSA and Shor's algorithm | 2 | | |
| 11. QML 1<br>• Encoding classical data into quantum states<br>• Parametrized quantum circuits<br>• Hybrid models | 2 | | |
| 12. QML2<br>• Variational quantum algorithms<br>• Quantum kernel methods | 2 | | |
| 13. QML3<br>• HHL, QGAN algorithms | 2 | | |
| 14 Applications & outlook<br>• Current hardware limits<br>• Where QML might realistically help | 2 | | |


Bibliography:

- Nielsen and Chuang, Quantum Computation and Quantum Information, Cambridge University Press (2010).
- David McIntyre, Quantum Mechanics: A Paradigms Approach, Pearson Addison-Wesley (2012).
- Cohen-Tannoudji, Quantum Mechanics, Wiley-VCH; 2nd edition (2019).
- Maria Schuld & Francesco Petruccione, Machine Learning with Quantum Computers (Springer, 2021, 2nd ed.)


| **9.2 Applications - Seminars/Laboratory/Project** | Hours | Teaching methods | Notes |
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|---|---|---|---|
| 1. Visualising qubit operations: Bloch sphere, single qubit gates, destructive and constructive interference (Quantum Odyssey) | 2 | Lab work in INCDTIM Quantum Software lab, using tools such as Uranium, Quantum Oddyssey, Google Colab. | |
| 2. Quantum circuits in Uranium/Qiskit | 2 | | |
| 3. Generating entanglement in quantum circuits (quantum gates: CNOT, SWAP, Toffoli). Visualisation in Q. Odyssey, circuits on the Uranium platform. | 2 | | |
| 4. Deutsch algorithm/Grover algorithm | 2 | | |
| 5. Quantum Fourier Transform | 2 | | |
| 6. Variational algorithms | 2 | | |
| 7. HHL algorithm | 2 | | |

Bibliography


- Nielsen and Chuang, Quantum Computation and Quantum Information, Cambridge University Press (2010).
- David McIntyre, Quantum Mechanics: A Paradigms Approach, Pearson Addison-Wesley (2012).
- Cohen-Tannoudji, Quantum Mechanics, Wiley-VCH; 2nd edition (2019).
- Maria Schuld & Francesco Petruccione, Machine Learning with Quantum Computers (Springer, 2021, 2nd ed.)


*Se vor preciza, după caz: tematica seminariilor, lucrările de laborator, tematica și etapele proiectului.*

**9. Bridging course contents with the expectations of the representatives of the community, professional associations and employers in the field**

**10. Evaluation**

| Activity type | Assessment criteria | Assessment methods | Weight in the final grade |
|---|---|---|---|
| Course | Solving 2 problems + 1 theory set of questions | Written exam | 60% |
| Seminar | | | |
| Laboratory | - | Periodic lab quizzes | 40% |
| Project | - | - | - |
| Minimum standard of performance: | | | |

| **Date of filling in:** 29.04.2026 | **Responsible** | **Title First name Last name** | **Signature** |
|---|---|---|---|
| | Course | Dr. Liviu ZARBO | |
| | Applications | Dr. Liviu ZARBO | |
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| Date of approval in the department | Head of department,<br>Prof.dr.eng. Rodica Potolea |
| Date of approval in the Faculty Council | Dean,<br>Prof.dr.eng. Vlad Mureșan |