

# QUANTUM COMPUTING MASTERCLASS

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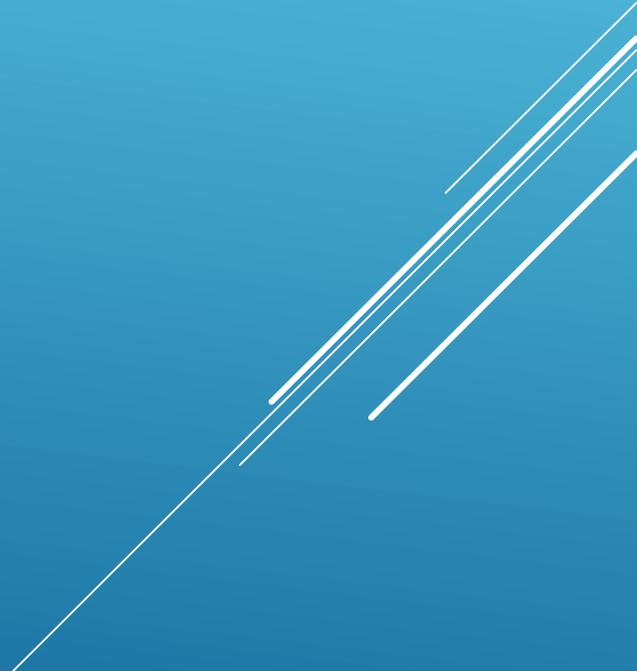
*in collaboration with*

**IBM Q-Experience Team, Italy**

There is a quantum computing race among some tech giants like Google, IBM, Rigetti and Microsoft, including to a lesser extent Amazon and China's Alibaba. Governments are funding work in the area with the concern that quantum computers may soon crack current encryption methods, giving the country that gets there first a major advantage. Many universities worldwide have some activity in quantum computing, and considerable funding is also available worldwide. There is the need in **introducing quantum computing and encouraging schools to join us in this revolutionary step forward for computing.**

The Quantum Computing MasterClass is a **graduate-level quantum computing introduction to elementary problems to be solved on IBM's Q Experience quantum computing simulator.**

## Topics will include :

- ✓ learn the background material in computer science and physics necessary to comprehend quantum computing
  - ✓ understand basic quantum computing circuits, particularly quantum gates, and comparison with classical computing gates
  - ✓ understand the physical realization of quantum computers
  - ✓ understand the central results of quantum computing
  - ✓ develop initial expertise in writing simple programming codes for quantum computers.
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The **Quantum Computing MasterClass** has student projects that utilize hands-on labs with simplified quantum program development, live code executions and student projects performed using IBM's Quantum Experience Platform with access to real Quantum Computers.

The MC will use the free-access **5 Qubit computer within IBM Research Labs.**

The projects will address three types of problems:

- **Computing an algebraic operation by using qubits in a "classical" mode**

Implementing the use of quantum computer to evaluate a simple operation by using qubits

- **Placing qubits in super positions**

Creating the superposition of quantum states to understand the basic idea of quantum mechanics

- **Implementing quantum entanglement**

Implementing an algorithm which gives a direct evidence of the entanglement

Topic 1 *to cover the visualization of a quantum bit ("qubit"), introduction to the  $|\text{ket}\rangle$  notation for vectors in quantum computing, explanation of gates, and an introduction to matrix notation for kets, or vectors, and gates.*

An introduction to the **concept of measurement** is also included. The pre-measurement state, when the quantum computing program is running and the qubit is in a quantum state, was contrasted with the post-measurement state, when the qubits are measured and the quantum waveform collapses and is read as either 0 or 1.

The **layout of the Composer** is reviewed and the method for selecting whether to run the program on the simulator or on one of the real quantum computers that IBM has made available was explained.

	Q0	Q1	Q2	Q3	Q4
Frequency (MHz)	5.25	5.30	5.35	5.43	5.18
T1 (μs)	48.40	48.60	42.20	41.80	51.40
T2 (μs)	43.50	18.20	30.80	15.80	11.90
Gate error (10 <sup>-3</sup> )	0.69	7.82	1.20	2.06	1.55
Readout error (10 <sup>-3</sup> )	5.70	6.70	3.60	2.50	10.50
MultiQubit gate error (10 <sup>-3</sup> )		3.11	2.20	6.75	5.56
			CX2_1	CX3_4	
				3.52	4.69

Annotations in the image:

- q = quantum register
- start at "new" (with arrow pointing to New button)
- zero ket (with arrow pointing to q[0])
- the score (with arrow pointing to the circuit)
- "c" = classical computer (with arrow pointing to the 'c' register)

Annotated user interface of the IBM Composer

## Topic 2 to cover *superposition*.

To understand the diagrams illustrating superposition, they had to be introduced to the Greek symbol psi,  $\Psi$ , as superposition can be shown as a psi  $\Psi$   $|\text{ket}\rangle$  (to show all of the possibilities, psi  $\Psi$ , of a vector  $|\text{ket}\rangle$ , in superposition: the psi-ket is depicted as  $|\Psi\rangle$ ).

Superposition is created by applying a Hadamard (H) gate to a qubit.

$$|\Psi\rangle = \frac{|\text{giraffe}\rangle + |\text{snake}\rangle}{\sqrt{2}}$$

*Quantum superposition*

### Topic 3 to cover *entanglement*.

Entanglement means that two or more qubits have formed a relationship. The entanglement is created by the program applying an H gate to the one qubit and then a Controlled-Not (CNOT) gate to two qubits, **the control qubit and the target qubit**. They can be separated by large distances, yet always remain entangled with one another – if one is changed by a new gate, the other changes instantly in the same way. It was explained that there is no violation because the message noting that the change occurred is still limited by  $c$ .

The hands-on portion of the class was to make CNOT connections in the IBM Composer, use X gates (X gates flip values from zero to one and one to zero), to predict their answers, and run the program. To do this, the students had to study the diagram that accompanies the programming interface of the Composer, to identify legitimate paths for entanglement of qubits.

**Review of Superposition** included the Bloch Sphere as an illustration of a qubit, and the  $|\Psi\rangle$  vector within that sphere with its nearly infinite possibilities between zero and one, will be proposed.

# Quantum Computing MC 2021

## Orientation

For the MC a full orientation is in order. This can be done online, in classroom and with seminars in site. The orientation will cover

- Classroom preparation for the MC
- Trying a QC exercise
- Walk through a MC logistics
- MC library
- Connection test
- Q&A

The seminars visit takes generally 3 hours for two days, though it can be extended on demand.

The MC orientation can be obtained by [registering on a prepared Google form](#).

## MC Workshop

The MC workshop will be organized as follows (tentative)

- Classroom preparation for the MC
- Trying a QC exercise
- Walk through a MC logistics
- MC library

Connection test

(\*) The seminar will be frontal at the participating Institute

DAY 1 - Orientation	
Time	Activity
09:30	Introduction to MC
10:00	Classroom preparation for the MC
10:30	MC Logistics
11:00	Pause
11:30	The Library
12:00	A simulation
12:30	Pause
14:30	Discussion
16:00	end-of-the-day

DAY 2 -	
Time	Activity
09:00	Introduction to MC
09:30	Seminar 1 (*)
10:00	Seminar 2 (*)
11:00	Pause
11:30	Seminar 3 (*)
12:30	Lunch
14:00	Seminar 4 (*)
15:00	Discussion
16:00	end-of-the-day

DAY 3 – The MC	
Time	Activity
09:00	Recap
09:15	Visit
10:00	Tutorial QC by IBM – video conference
12:30	Lunch
14:00	MC Lab by IBM – video conference
16:00	Break
16:15	Discussion – video conference
17:00	end-of-the-day

## **Classroom Preparation**

- explain the basic aspects of quantum computing
- use a quantum computer free available
- discuss the main differences with respect to classical computing
- give an introduction to hardware underlying the new quantum computing schemes

## **MC Classroom**

All technical information for web connection and video-conference learning will be shared with participants

## **Institute**

Previous to day of the MC:

Orientation for mentors and teachers by MC staff or fellow (2h)

Classroom preparation of students by teacher (3h)

## **Masterclass Day:**

Registration

Icebreaker activity

Mentor presentation

Lab tour

Teacher presentation on MC QC activity

Lunch with a physicist

QC MC activity by students with help of mentor, teachers, other physicists

Discussion of combined results for Institute

Video Conference

Wrap-up

Attendance form

## Quantum Computing

The benefits of IBM Composer used with the high school teaching environment were the following:

**IBM Composer is all on the web**, so it took only the one step of having the high school technical support security policy decision maker to make the URL available. The students could get hands on with the tool right away after IBM registration, which took only minutes.

**IBM Composer includes descriptions of the gates, includes QASM, and includes a diagram of the arrangement of the qubits in the quantum computer being programmed.** The User Interface is intuitive, at least, to a high school student. Well-placed error messages, such as a reminder to save the program before running it, pop-up to assist.

**Quantum programs written in IBM Composer can be run on either real quantum computers or on the simulator.** Sometimes at periods of high traffic, the real quantum computers delayed giving their results by a few hours or a day.

For the classes given to the high school students, running the programs on the real machine were limited to where it made a significant difference in the results. **The simulator also offers a range of configuration options and that can be designed by the student to try different ideas.**

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