

Teaching hands-on quantum computing to youth through workshops

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Outline

- Motivation
- Effective Teaching strategies
- Design and delivery of workshops
- Our observations
- Upcoming workshop – “Demystifying quantum enigmas: a hands-on introduction to quantum computing”

Why should we teach quantum computing at a high-school level?

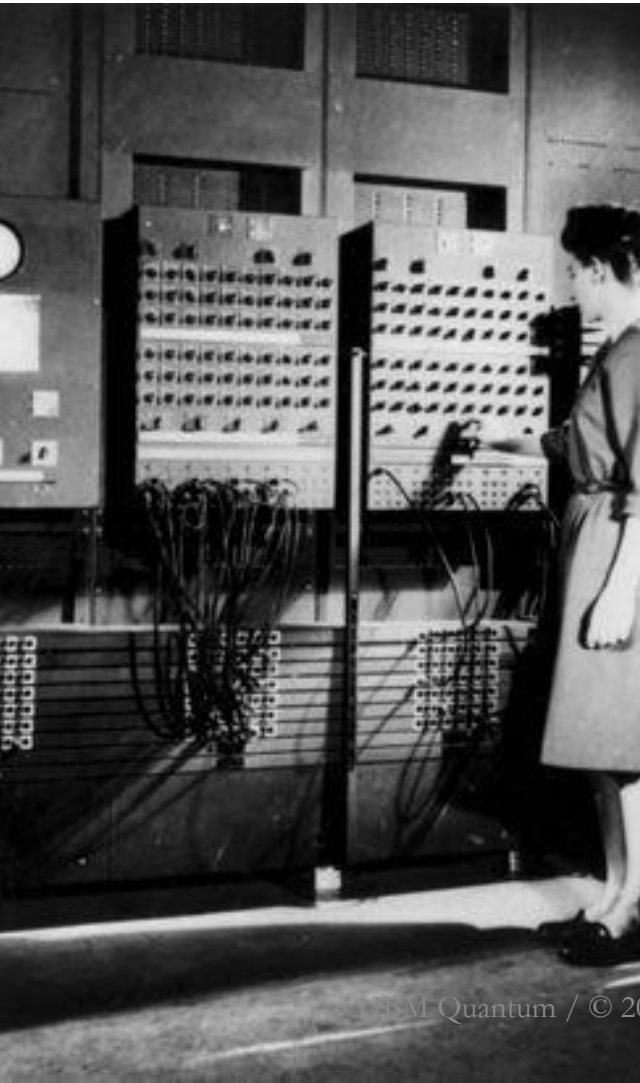
Why does it matter whether people understand anything about quantum computing?

Motivation

Why is quantum computing
important?

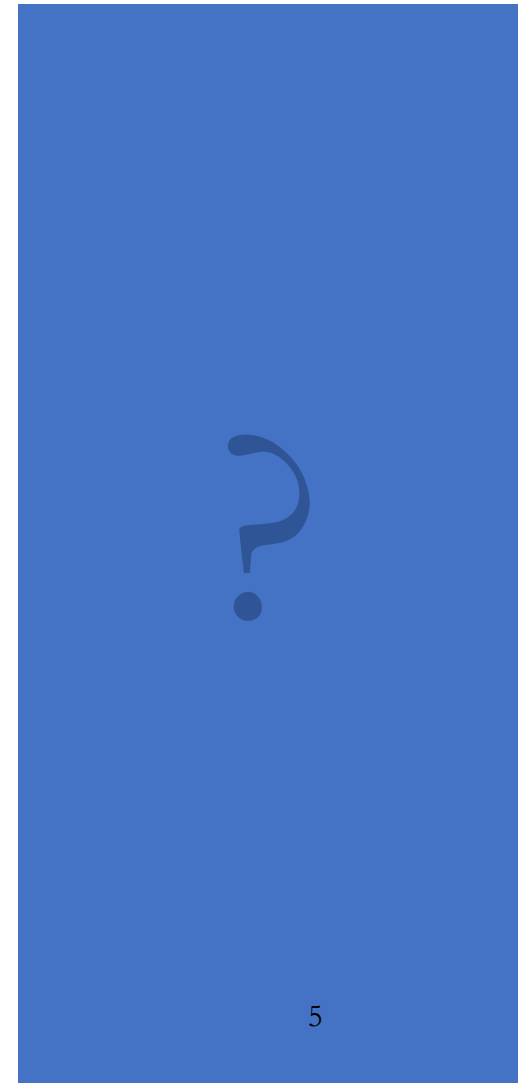
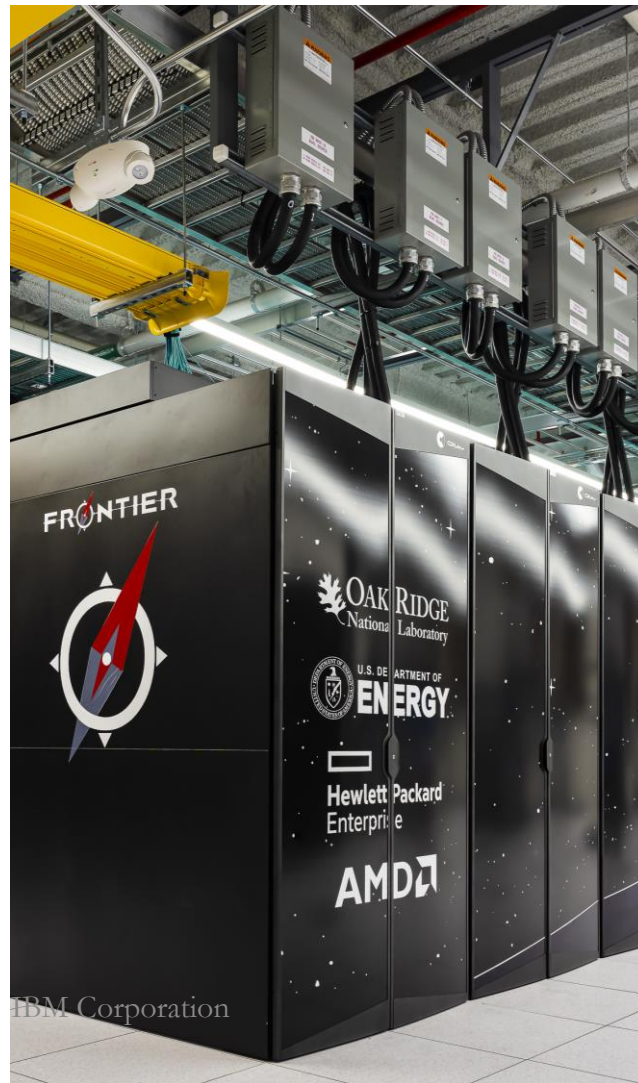
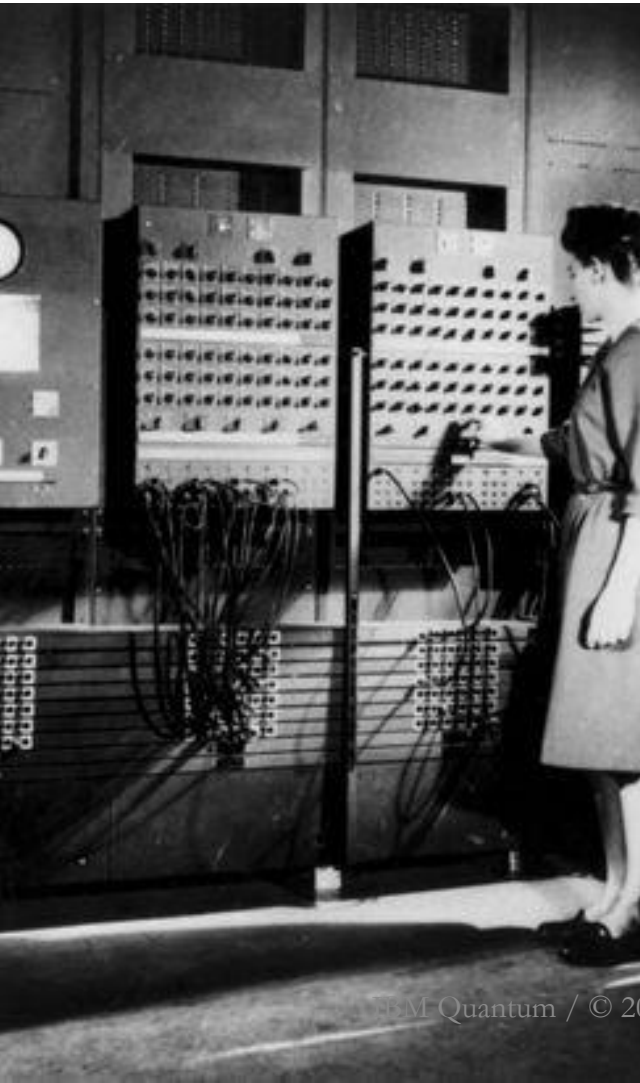
Computing

Making physics do the hard work since 1822



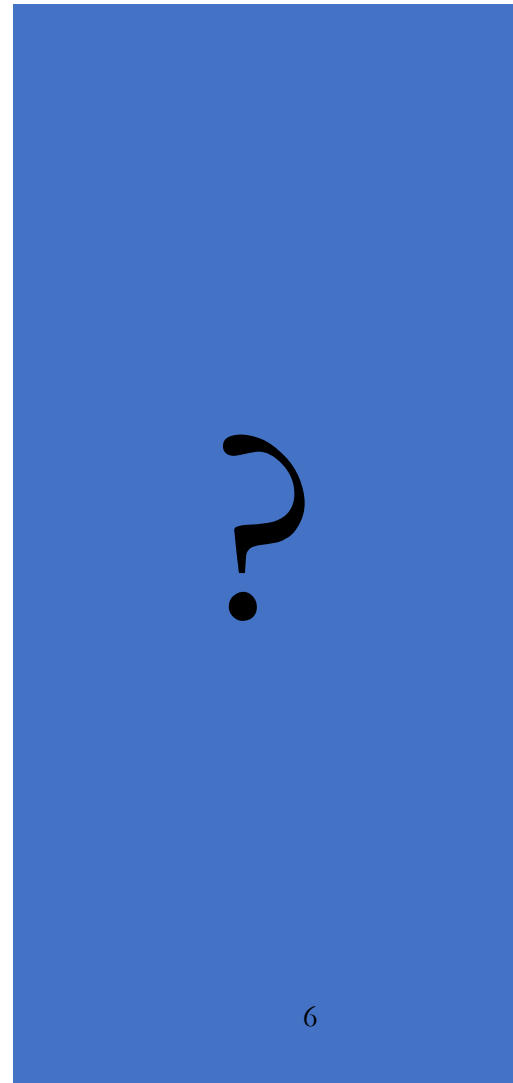
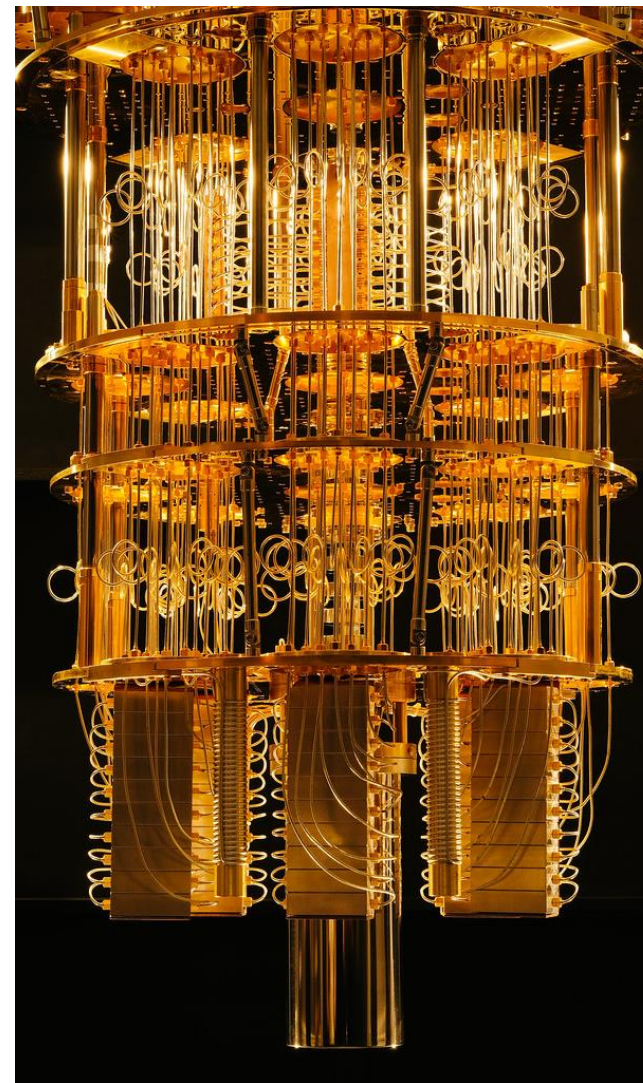
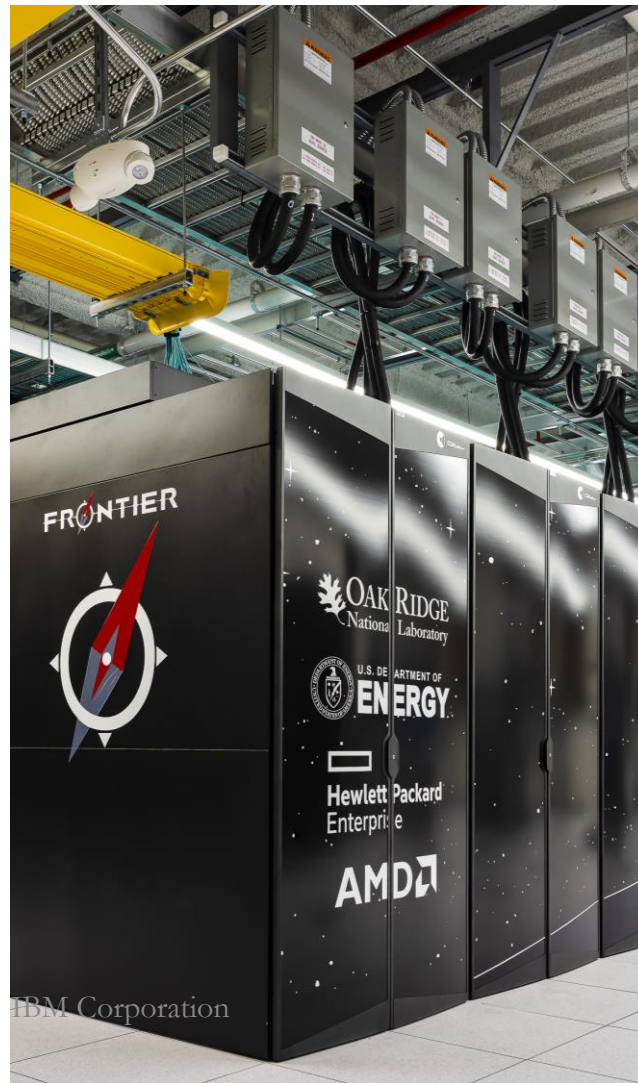
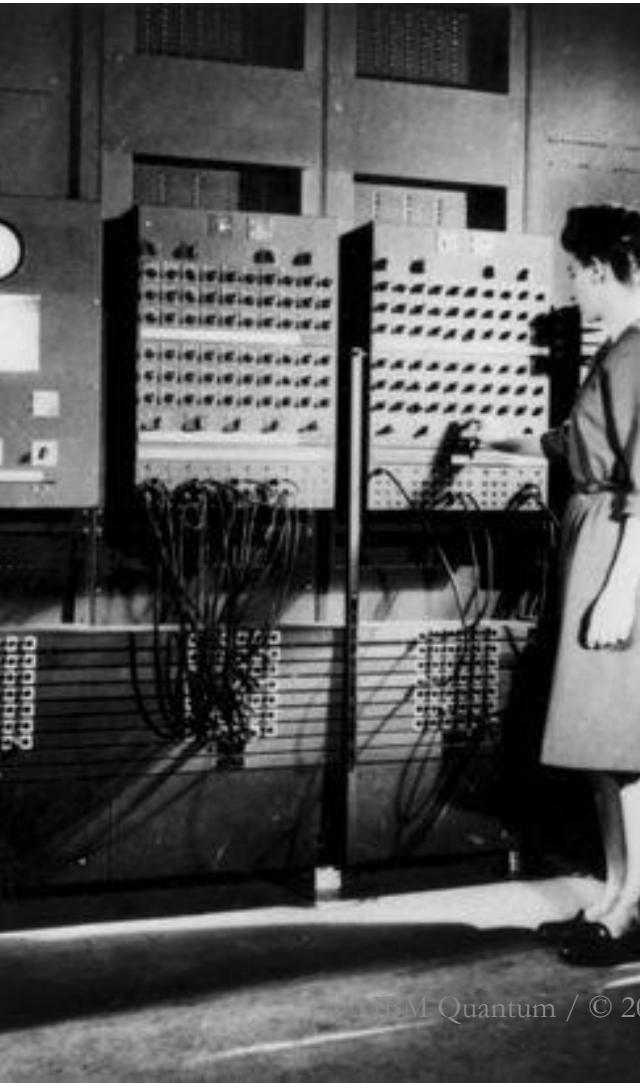
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Computing

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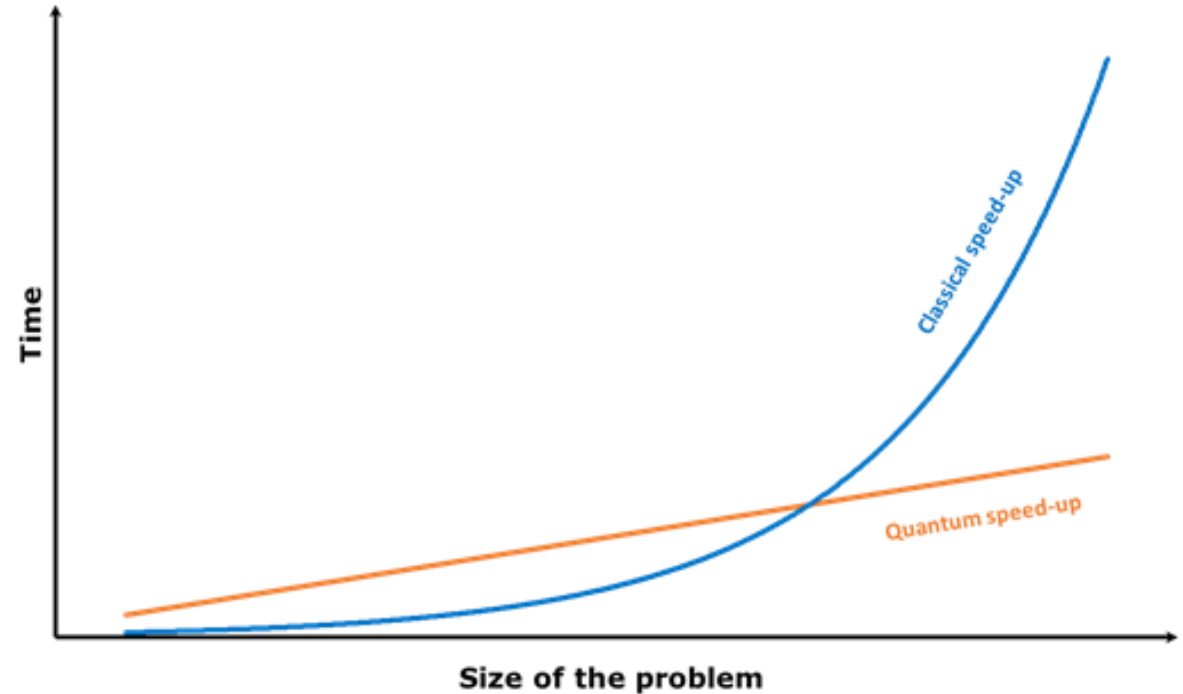


Quantum is interdisciplinary

Why does it matter whether people understand anything about quantum computing?
What changes are likely to happen due to developments in quantum computing?

Potential to revolutionize

- Chemistry: simulating molecules, efficient fertilizer production, designing catalysts
- Cryptography: integer factorization, key distribution
- Optimization: Supply chain logistics, portfolio optimization
- And many other fields ...




Our workshops

Goals, strategies, and
observations

Goals of our workshops

- Long-term: Expose youth to quantum computing concepts early to provide career path choices
- Increase diversity: Attracting a diverse student body remains a challenge, early education helps
- Provide training resources: a significant amount of trained personnel are needed in the coming years
- Help K-12 curriculum development: we show how to involve youth in quantum computational thinking as early as possible



Effective teaching strategies

- Unplugged activities
- Practice Sheets
- Programming
- Quantum Games

Linear algebra and complex numbers

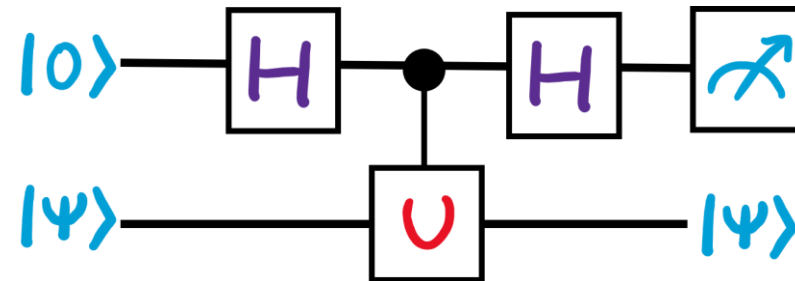
- Prerequisites for understanding the mathematics involved in quantum computing are rarely taught in high schools
- How do we teach high-schoolers?
 - Use only real numbers
 - Use the dirac notation

States:

$$|0\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \quad |1\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

Gates:

$$H = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

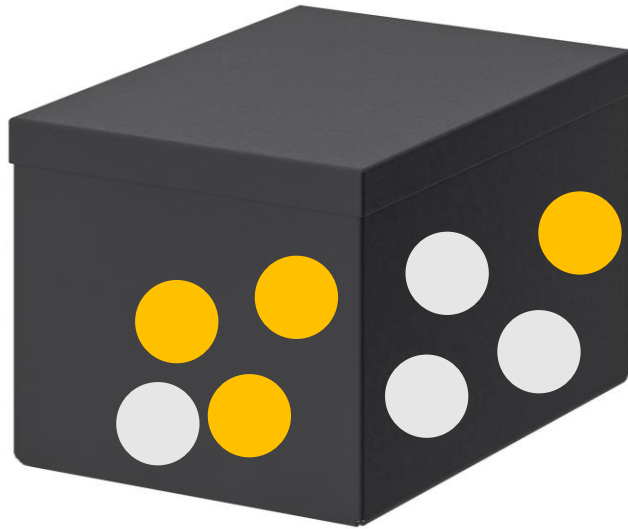


$$H |0\rangle = \frac{1}{\sqrt{2}} (|0\rangle + |1\rangle)$$

Unplugged activities



Qubit Doughnuts



Measurement black box



$$\frac{1}{\sqrt{2}}$$

$$\frac{1}{\sqrt{2}}$$

Find your quantum partner

Practice sheets

What is a valid quantum state?

$$|\psi\rangle = \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$$

$$|\psi\rangle = \frac{1}{4}|0\rangle + \frac{3}{4}|1\rangle$$

$$|\psi\rangle = \frac{12}{13}|0\rangle + \frac{5}{13}|1\rangle$$

$$|\psi\rangle = \frac{4}{5}|0\rangle + \frac{2}{5}|1\rangle$$

What's the state after applying the gates?

$$|1\rangle \xrightarrow{X} \xrightarrow{X} ?$$

$$|0\rangle \xrightarrow{H} \xrightarrow{X} ?$$

$$|0\rangle \xrightarrow{X} \xrightarrow{H} \xrightarrow{H} \xrightarrow{X} ?$$

$$\frac{|0\rangle - |1\rangle}{\sqrt{2}} \xrightarrow{H} \xrightarrow{H} ?$$

Measurement

$$|1\rangle \xrightarrow{X} \xrightarrow{X} |1\rangle \xrightarrow{\text{Measurement}} ?$$

$$|0\rangle \xrightarrow{H} \xrightarrow{X} \frac{|0\rangle + |1\rangle}{\sqrt{2}} \xrightarrow{\text{Measurement}} ?$$

$$|0\rangle \xrightarrow{X} \xrightarrow{H} \xrightarrow{H} \xrightarrow{X} |0\rangle \xrightarrow{\text{Measurement}} ?$$

$$\frac{|0\rangle - |1\rangle}{\sqrt{2}} \xrightarrow{H} \xrightarrow{H} \frac{|0\rangle - |1\rangle}{\sqrt{2}} \xrightarrow{\text{Measurement}} ?$$

Programming

- IBM Circuit Composer
- Python + Qiskit

The screenshot displays the IBM Quantum Composer interface. At the top, the title bar reads "IBM Quantum | Composer" and includes a "Sign In" button. Below the title bar, there are menu options: "Untitled circuit", "File", "Edit", and "View". The main workspace is divided into several sections:

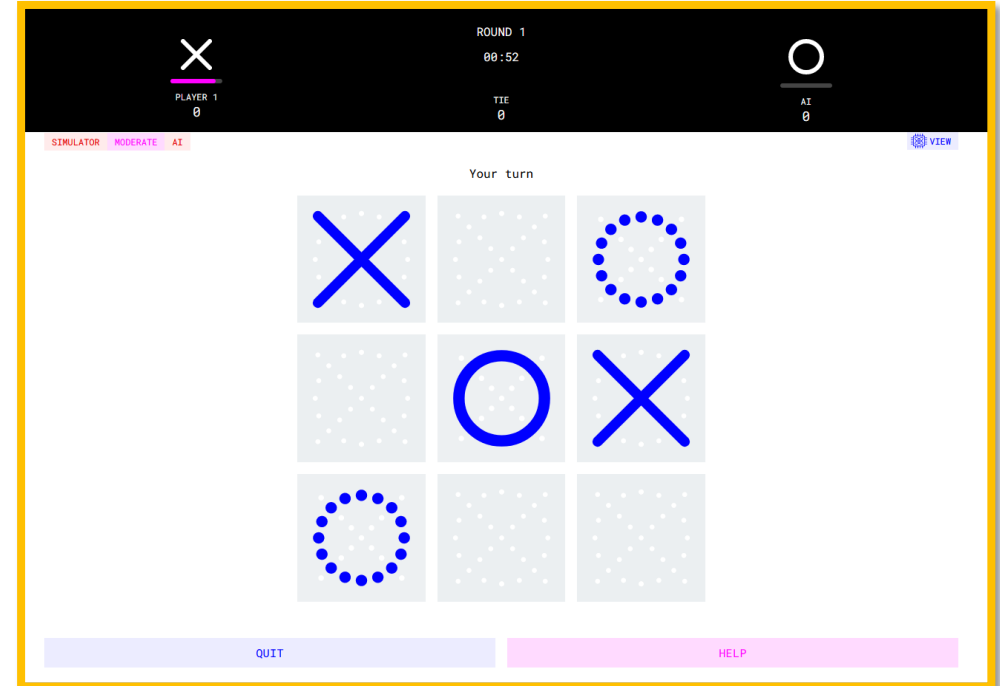
- Operations:** A toolbar with various quantum gates and operations, including H, T, S, Z, T†, S†, P, RZ, √X, Y, RX, RY, RXX, RZZ, U, RCCX, and RC3X.
- Circuit Diagram:** A visual representation of a quantum circuit with four qubits (q[0], q[1], q[2], q[3]) and a classical control line (c4). The circuit includes an H gate on q[0], a CNOT gate from q[0] to q[1], a T gate on q[1], an S gate on q[1], a CNOT gate from q[1] to q[2], a CNOT gate from q[1] to q[3], and a CNOT gate from q[0] to q[3].
- OpenQASM 2.0 Code:** A text editor showing the following code:

```
1 OPENQASM 2.0;
2 include "qelib1.inc";
3
4 qreg q[4];
5 creg c[4];
6 h q[0];
7 cx q[0], q[1];
8 cx q[1], q[2], q[3];
9 tdg q[1];
10 s q[1];
11 swap q[0], q[1];
12 swap q[1], q[2];
```
- Probabilities:** A bar chart showing the probability distribution of computational basis states. The x-axis lists states from 0000 to 1111, and the y-axis shows probability from 0% to 100%. The states 0000 and 0101 have the highest probabilities, both around 50%.
- Q-sphere:** A 3D visualization of the quantum state on a Bloch sphere. The state is represented by a purple dot at the top pole (|0000⟩) and a pink dot at the bottom pole (|0101⟩). A legend below the sphere indicates the phase angle, with a checked box for "State" and an unchecked box for "Phase angle".

Quantum Games



Entanglion



Quantum Tic Tac Toe

Design and delivery of workshops

| | |
|-----------------------------------|--|
| Introduction | Journey of a qubit: A quick introduction Main concepts: Qubits, Superposition, Entanglement, Measurement, Quantum Gates Create IBM accounts, setup environment Hands On: Circuit Composer |
| Journey through the quantum stack | Quantum Software: Hands On: Quantum gates and circuits Quantum applications with a focus on hybrid quantum-classical techniques |
| Pathways into Quantum Computing | Panel Discussion: How did you get into quantum computing? Q & A with students |

Sample of a one day workshop schedule

Our observations



Teaching strategies: A mix of strategies helped for an interactive learning experience.



Engagement and participation: Interaction among participants lead to high student satisfaction.



Diversity: Attracted interest from various age groups, promoting collaboration and synergy.

Our observations



Props and handouts: unplugged activities and practice sheets for reinforced learning.



Programming: The composer was easy to use, Jupyter notebooks and python had lower levels of comfort



Gamification: "Entanglion" game enjoyed by students, although its complexity and timing posed challenges in identifying learned concepts.



Panel discussion: Rich discussion into careers in quantum

Take home messages

Why should we teach quantum computing at a high-school level?

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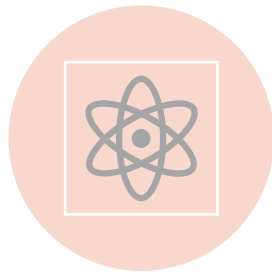
- Preparing for the future
- Developing critical thinking and problem-solving skills
- Introducing interdisciplinary connections
- Broadening perspectives
- Encouraging creativity and innovation

Take home messages

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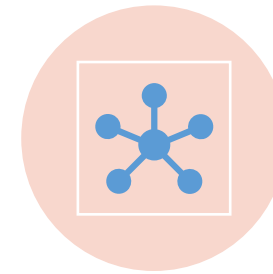
BASIC QIS IS NOT ANY
HARDER THAN BASIC
ALGEBRA TAUGHT IN
SCHOOLS



COMPUTING + QUANTUM
COMPUTING = A GREAT
TOOLKIT!



LEARN QUANTUM PHYSICS
AND MATHEMATICS
THROUGH QUANTUM
COMPUTING



PROVIDE OPPORTUNITIES
TO ENGAGE IN THE LOCAL
QUANTUM ECOSYSTEM

Resources

- Perry et al., Quantum computing as a high school module: <https://www.osti.gov/biblio/1527395>
- Qubit by Qubit: <https://www.qubitbyqubit.org/>
- Angara et al., Teaching Quantum Computing to High-School-Aged Youth: A Hands-On Approach: <https://ieeexplore.ieee.org/abstract/document/9613752>

Upcoming workshop



**Demystifying
the Quantum Enigmas**
A hands-on introduction
to quantum computing

September 17, 2023 10:30am
Online Workshop

15\$ registration fee
Limited places available

<https://qce.quantum.ieee.org/2023/>