

Training for Educators

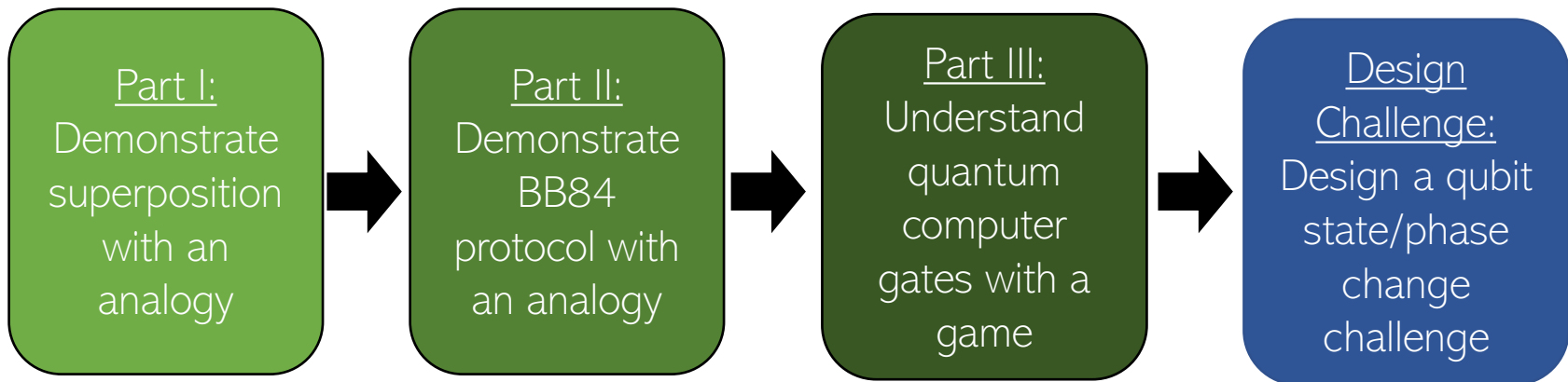
Quantum Computing

Secondary Level
Ages 12-18

Purpose of the lab

- The purpose of this lab kit is to learn about quantum computing through experiments and activities. Students will learn about the difference between classical bits and qubits and the concepts of superposition and entanglement. Students will also engage in activities that teach them about quantum cryptography and quantum computing through games and analogies.
- The main takeaways are:
 - Superposition is a state in which a bit exists both as a 0 and 1 simultaneously. To collapse the superposition state, the qubit is measured.
 - The BB84 protocol is a quantum cryptography protocol that utilizes photons to create a secret key.
 - Quantum computer gates are fundamentally different than classic computer gates in that both the state and the phase of the bit are relevant.

Summary of experiments



There are 3 experiments/activities in total.

Supplies list

- Coins (metal with two distinct sides)
- Opaque cups
- Paper
- Wrapped candies (or small pieces of paper)
- Buckets or jars
- Markers
- Colored tape (red and green) (2 other colors may also be used)
- Save Schrödinger's Cat game pieces for each group:
 - 8 blue cat/red cat tokens to act as qubits
 - 8 yellow cat/green cat tokens to act as qubits
 - 2 X gates
 - 2 Y gates
 - 2 X gates
 - 2 S gates
 - 2 H gates
 - 1 CNOT gate
 - 1 qubit gate phase change table
 - 1 qubit Interference table
- Scissors
- Clear tape

Safety considerations

Before the students begin the laboratory, please take into consideration the following safety concerns:

- This lab kit has no major safety concerns associated with it.

Setting up your space

- Gather your supplies and separate by experiment(s) on your table.
- These are our recommendations:
 - Each student should have a pencil or pen.

Groups of 2-4 students can be given the following supplies:

- 1 coin (two distinct sides)
- 1 opaque cup
- 40 wrapped candies (or 40 pieces of paper)
- 2 buckets or jars
- Game pieces for Part III

The class can share the following supplies:

- Colored tape
 - Markers
- If doing the optional supplemental activity, groups should have access to computer with Python installed (or teacher can project program to students via screen).

Part I. Quantum Coin Flip

- Set-up:
 - Each group of 2-4 students gets 1 coin with two distinct sides and 1 opaque cup.
- Procedure:
 - Students should flip coin onto a table and cover it with the cup before revealing if it is heads or tails. The students should predict if coin is heads or tails and then lift the cup to “measure” the coin.
- Results:
 - Students will see that their percentages of measuring heads and tails will vary from the expected probability of 50% for each. If the coin represents a qubit, the student should see the coin under the cup is in a state of superposition and lifting the cup “measures” the coin.

The takeaway is that superposition is when something exists in more than one state simultaneously. To collapse the superposition state, the thing is measured.

Part II. Quantum Cryptography

- Set-up:
 - Each group (2-4 students) will need 40 pieces of wrapped candy (or 40 small pieces of paper) and 2 buckets or jars. The class can share colored tape and markers needed to distinguish the 40 candies.
 - Prepare the 40 candies: Students will write "0" on 10 candies and "1" on 10 candies and put red tape on 10 candies and green tape on 10 candies. The candies with numbers go in one jar and the candies with tape go in a second jar.
- Procedure:
 - Students will act as "Alice" or "Bob". Alice selects one candy from each jar and records the 0/1 (bit information) and color information. Alice passes the candy with 0/1 to Bob. Bob then selects one additional candy from the jar with different colored candies. Alice and Bob record their bit and color information and repeat the procedure 5-10 times. Alice and Bob then share their color information for their candies; if the colors match, they keep the information they recorded, and if the colors do not match, they discard the information they recorded.
- Results
 - Students should see the analogy between their candies and polarized photons used in the BB84 protocol. They should also see due to random chance Bob will have to discard his "photon" information 50% of the time.

The takeaway is the BB84 protocol is a quantum cryptography protocol that utilizes photons to create a secret key.

Part III: Quantum Computer Gates

- Set-up:
 - Each group (2-4 students) will need Save Schrodinger's Cat game pieces.
- Procedure:
 - Students will work through a game that uses quantum gates to change the state (Awake/Sleep) and phase (color) of bits (cats).
- Results
 - Students will see a variety of changes to their bits depending on the gates used.

The key takeaway is that quantum computer gates are fundamentally different than classic computer gates in that both the state and the phase of the bit are relevant.

Part III: Quantum Computer Gates

- Resources for Save Schrodinger's Cat game (American Physical Society PhysicsQuest):
 - https://www.youtube.com/watch?v=1OEqjGWOUhM&ab_channel=PhysicsCentral
 - <https://www.aps.org/learning-resources/save-schroedingers-cat>
- Additional video walkthrough:
 - Set-up:
[https://drive.google.com/file/d/1Xk1ssD6K84qJJ_oXOkrsFjkL1uKt5tPU9/view?usp=drive link](https://drive.google.com/file/d/1Xk1ssD6K84qJJ_oXOkrsFjkL1uKt5tPU9/view?usp=drive_link)
 - Procedure:
[https://drive.google.com/file/d/17izLX41CZpmHTINvzvYgCkOYJRPtq_6/view?usp=drive link](https://drive.google.com/file/d/17izLX41CZpmHTINvzvYgCkOYJRPtq_6/view?usp=drive_link)

Design challenge

Students are asked to build off the game from Part III to design a QubitCat change challenge. Students will first choose a cat and its state of being asleep or awake, and then they will try out a series of gates to change either its color or state. Once they have a change they like, they will write it down as a challenge (example: Take a (insert color) Cat that is (asleep/awake) and change it into a Cat that is (insert color) (insert state).)

- Questions to ask the students (encourage creativity)
 - What cat will you choose as your initial cat? Is it awake or asleep?
 - Which gates will you initially use with your cat to change its color or state? Brainstorm a few options and what you anticipate will happen.

Supplemental activity

- If computers are readily available and Python can be downloaded onto them, the supplemental quantum computing with Python and Qiskit can be completed
- Follow the procedure closely, which includes direct lines of code to use
- This supplemental activity will enable students to apply quantum gates to qubits and view the results