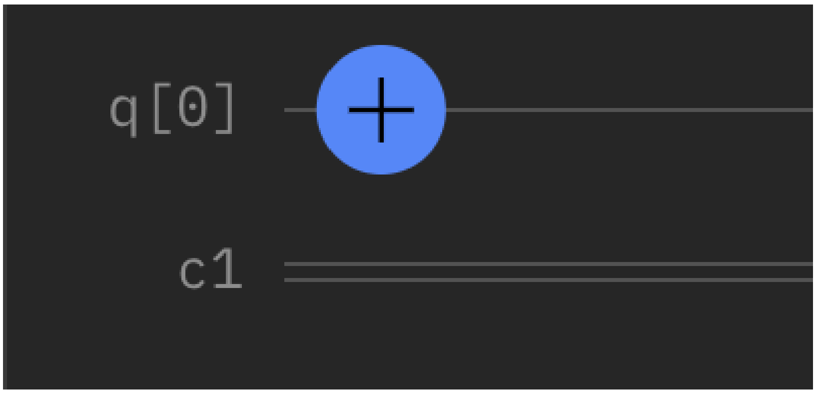
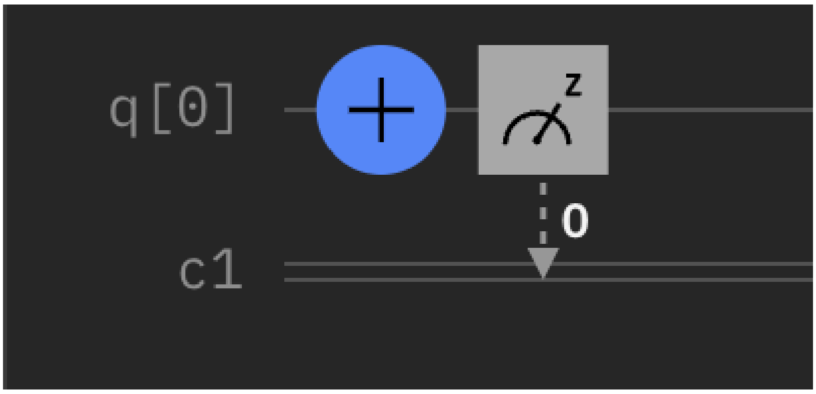
Module 3 Tutorial Solutions

1. Implementing X gate

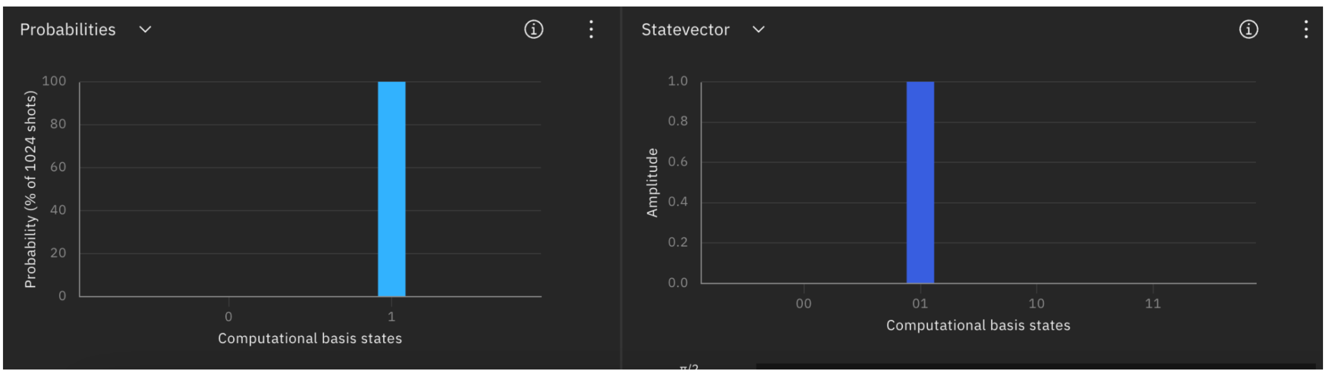
a. We start with |0⟩ state and apply the X gate



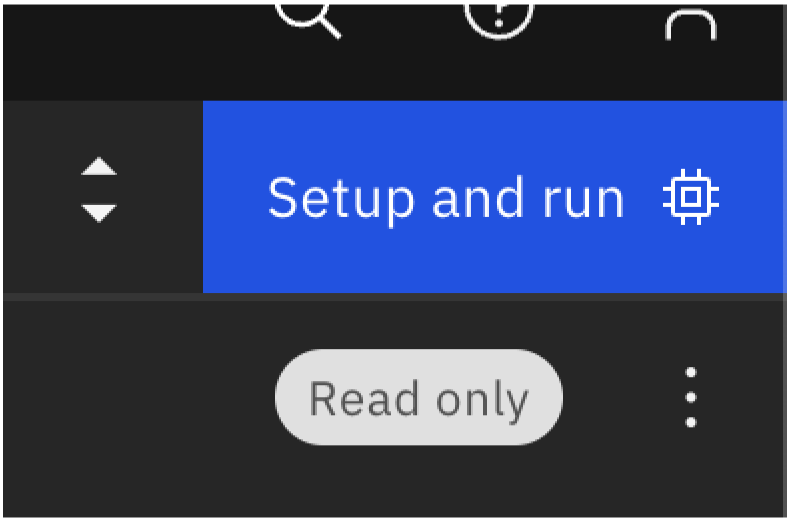
b. Add a measurement gate to the circuit to see the results of measuring the qubit to run the circuit on any simulator or device it must contain at least one measure operation, always make sure the number of classical bits is the same as the no of measurement operators in the system you can do this by clicking the bit labelled 'c' and adding or removing bits as you like



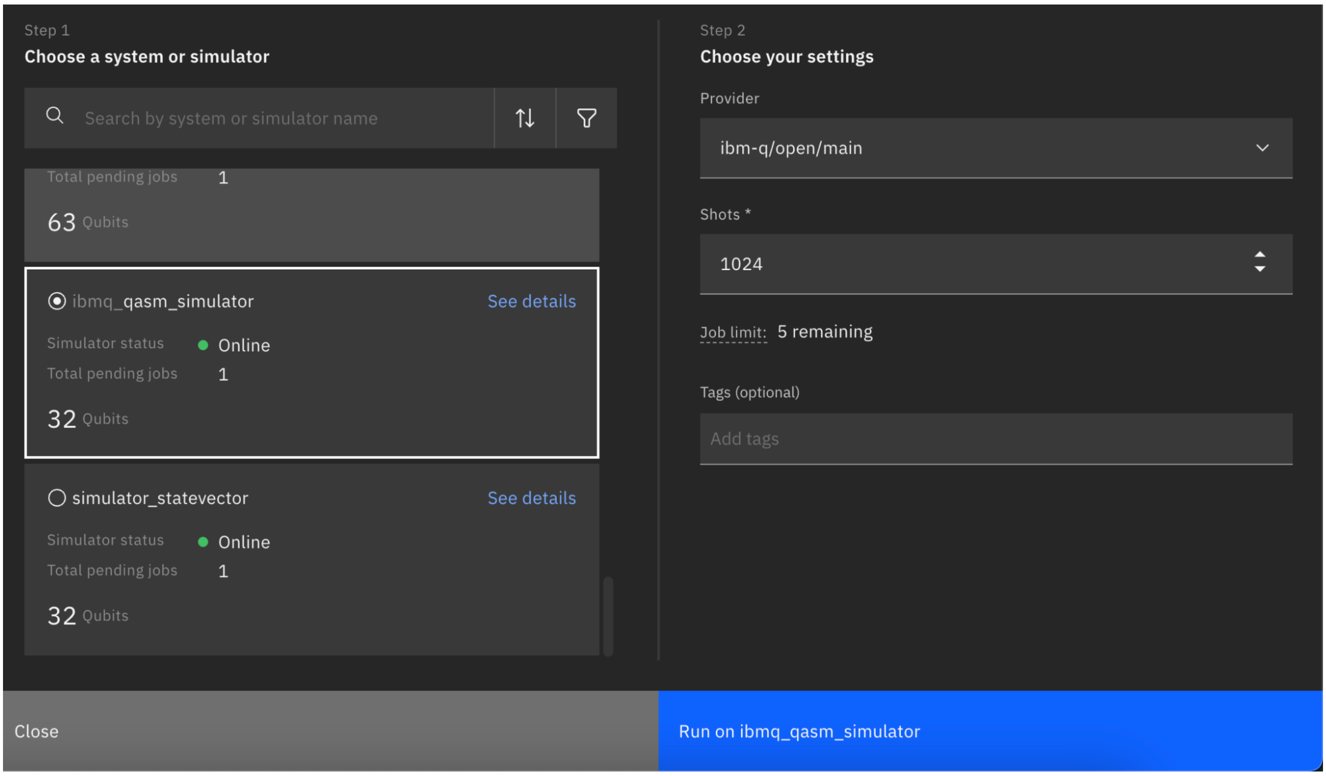
c. You can already see the probability distribution and the state vector of the final state in the bottom chart which evolves real time as you add gates in the circuit



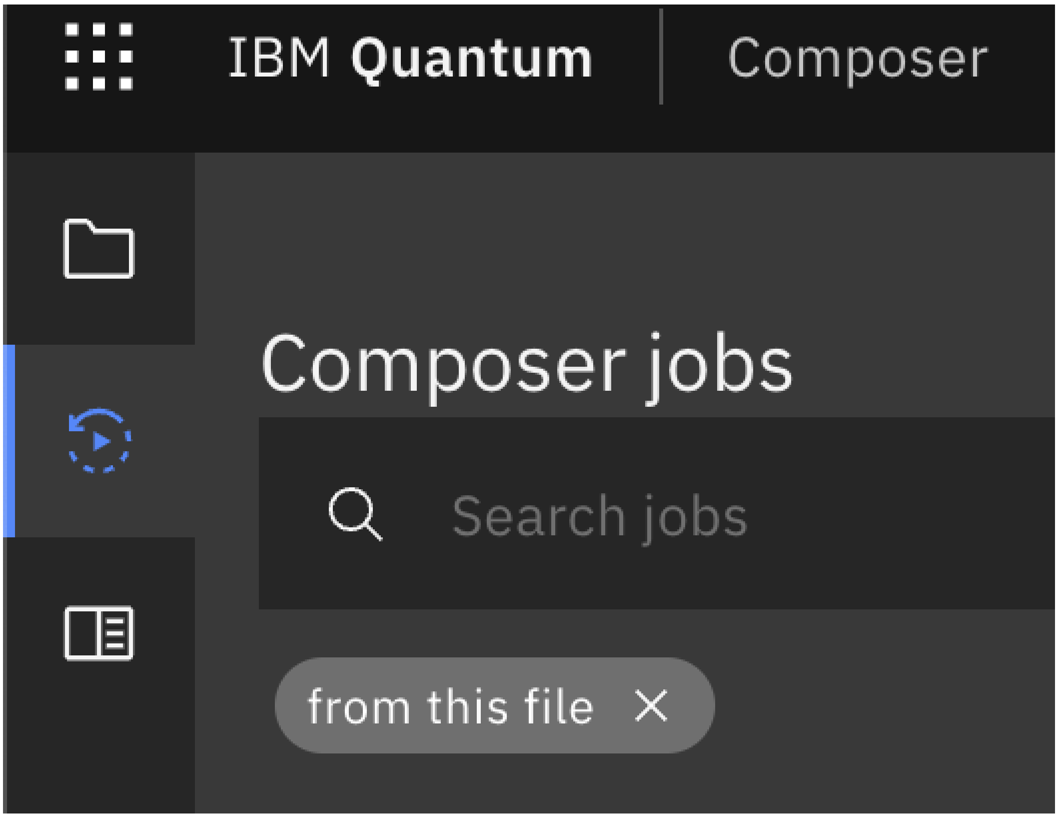
d. But to run the actual simulation of the circuit, on the top right of the composer you will wind the setup and run option which will give you access to all the available simulators



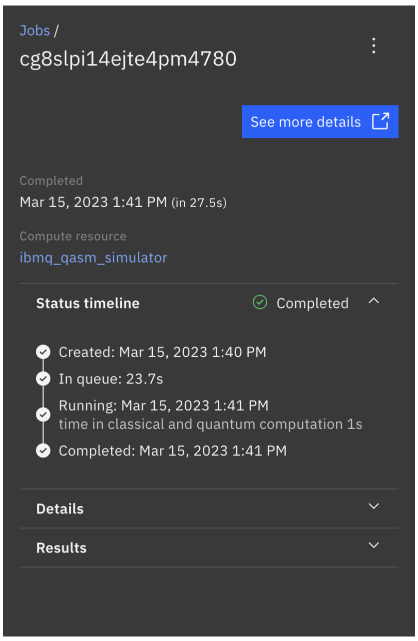
e. Choose a simulator from the list of options and change necessary configuration such as number of shots before running the circuit.



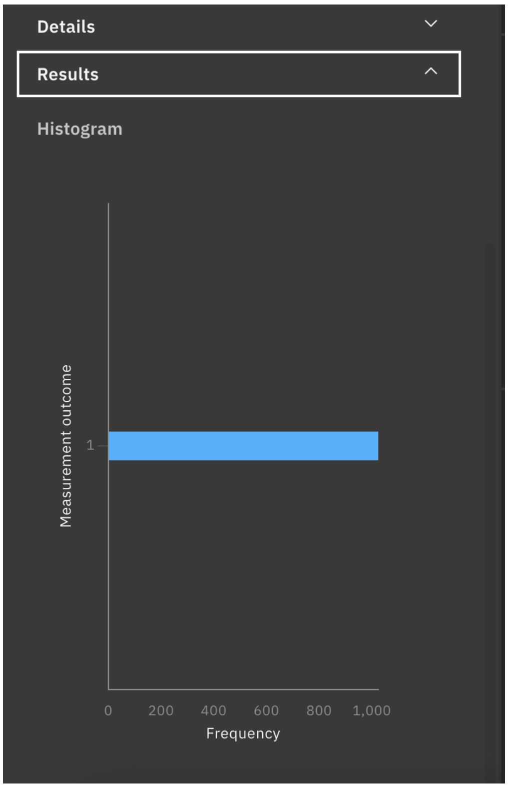
f. After running the job, all active jobs appear in the jobs pane on the left of the composer right below the files composer pane.



g. Find the active job in the list and wait for it run on the cloud, if the job remains in queue for very long just switch between the jobs window and the composer file pane there seems to be a glitch with IBM at the moment where the job appears in queue for very long



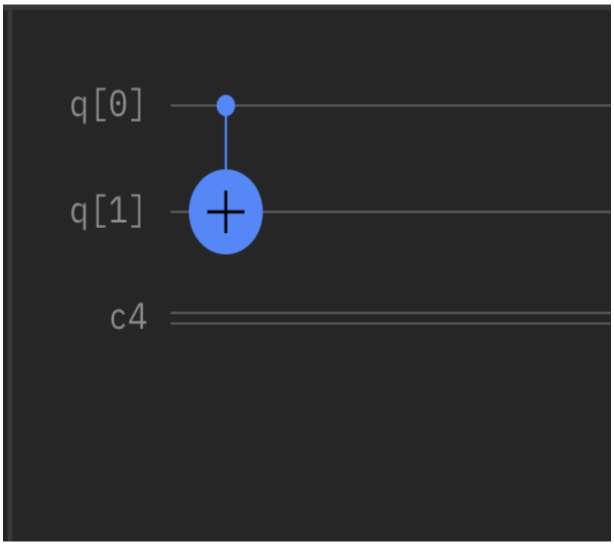
h. After completion of the experiment you can find the histogram of measurement results in the results section of the job and as shown here we have a 100% probability of being measured in state $|1\rangle$.

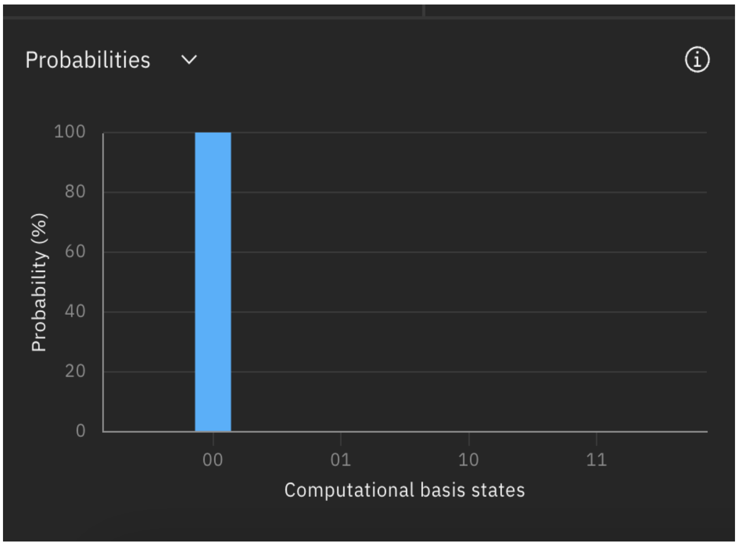


2. CNOT gate on state $|00\rangle$ and $|10\rangle$

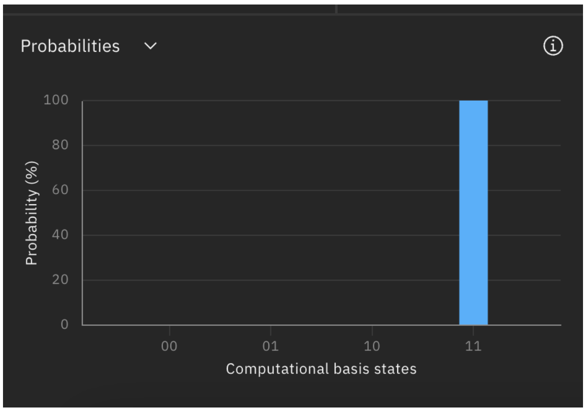
a. In this exercise we are meant to act the CNOT gate on state $|00\rangle$ and $|10\rangle$ to show that it in fact copies the stare from the control qubit to the target qubit but **only** for these particular basis states

b. First we build the following circuit for the $|00\rangle$ test this is just applying the CNOT gate on 2 qubits initialized in $|00\rangle$, obviously the result from this action is going to remain $|00\rangle$ as seen from the probability distribution





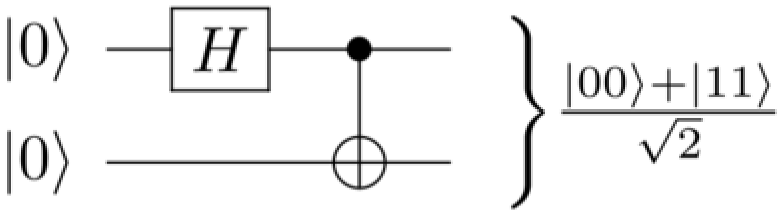
c. Similarly we can test the same input on the $|10\rangle$ input by acting an X gate on the control qubit and moving the state from $|00\rangle$ to $|10\rangle$ and then performing the CNOT gate to get the required result



3. Implementing all 4 bell states

a. In the tutorial we went through the construction of one of the bell states and showed the correlation between the measurement outcome of the 2 qubits, now we are going to learn how to construct the rest of the bell states and similarly observe the correlation of the measurement outcomes

Circuit for preparation of Bell state



4 Bell states : State vectors given below

$$|\Phi^+\rangle = \frac{|00\rangle + |11\rangle}{\sqrt{2}}$$

$$|\Phi^-\rangle = \frac{|00\rangle - |11\rangle}{\sqrt{2}}$$

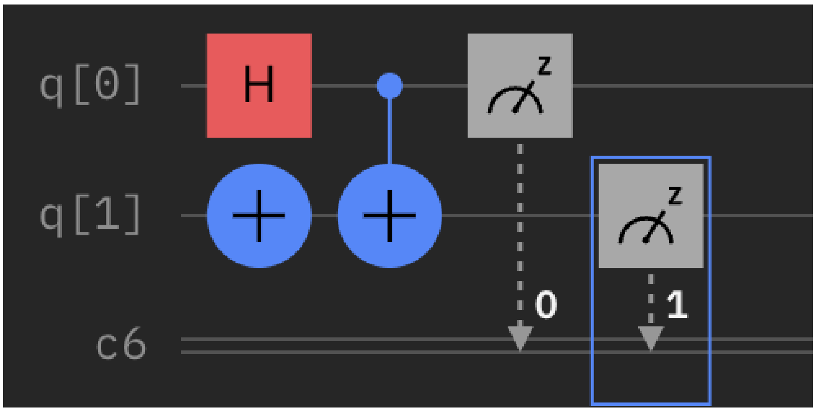
$$|\Psi^+\rangle = \frac{|01\rangle + |10\rangle}{\sqrt{2}}$$

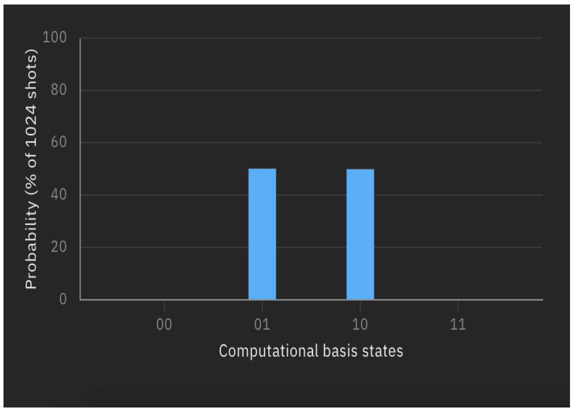
$$|\Psi^-\rangle = \frac{|01\rangle - |10\rangle}{\sqrt{2}}$$

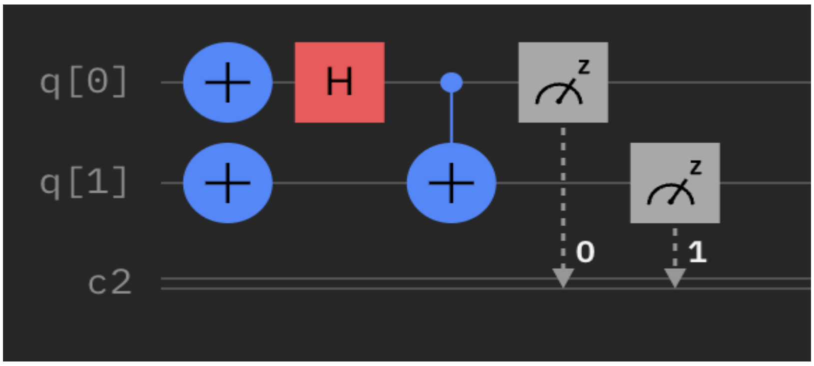
b. To get the remaining bell states the CNOT gate remains the same we just need to change the input to the CNOT gate, alternating between the diagonal states for the top qubit and the basis states for the bottom qubit. For the circuit that we built in the lecture the diagonal state was $|+\rangle$ and the basis state was $|0\rangle$. The other possibilities could be

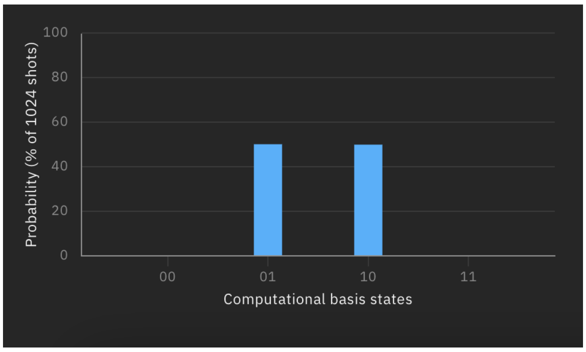
   i. Diagonal state $|+\rangle$ and basis state $|1\rangle$
   ii. Diagonal state $|-\rangle$ and basis state $|0\rangle$
   iii. Diagonal state $|-\rangle$ and basis state $|1\rangle$

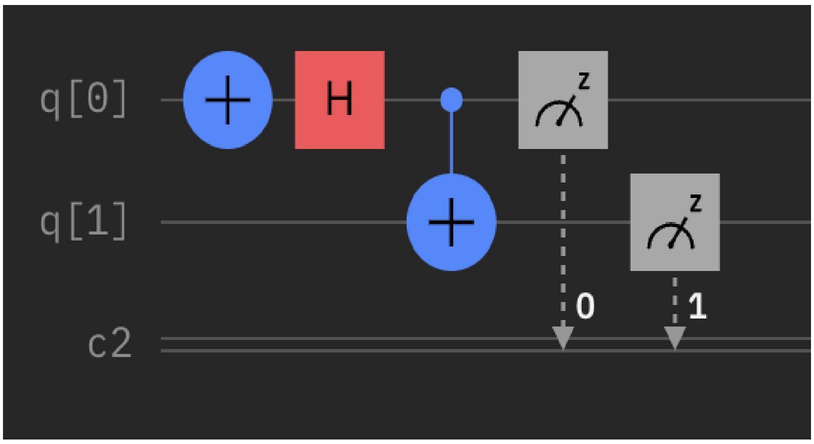
c. So to get the required circuits to implement these inputs we just need to add X gates to either the control qubit or target qubit or both which gives us the following three circuits with their corresponding measurement outcomes.

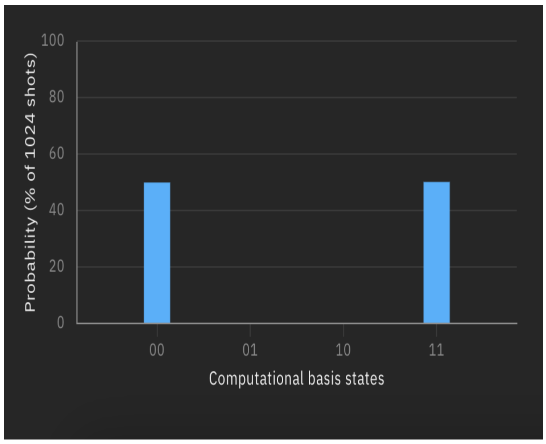












d. Here we can see the actual correlations between the results of measuring the 2 qubits as discussed in the tutorial, also as you can see the two pairs of bell states have the same measurement outcomes but as discussed they have a different relative phase.