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| **Learning Out come** | **Cell mapping** |
| M9 - From Probabilistic Systems to Quantum Systems | |
| 9.1 Students will understand the notion of probabilistic systems. | m9-ProbabilisticModel |
| 9.2 Students will be able to create probability vectors for probabilistic systems and apply simple operations on them. | m9-LookingAtTheStateMeasurement,  m9-quiz-9.1, m9-quiz-9.1-interactive, m9-Operation |
| 9.3 Students will understand the notion of qubits and types of operations that can be applied to them. | m9-FromClassicalToQuantum, m9-ProbabilitiesAndUnitaryMatrices,  m9-GoingForwardsAndBackwardsInTime,  m9-quiz-9.2, m9-quiz-9.2-interactive |
| 9.3 Student will understand about the Polarized Photon from a Classroom Experiment | m9-PolarizedPhotonExperiment, m9-SecondFilterExperiment, m9-ThirdFilterExperiment, m9-FilterOrientationExperiment, m9-quiz-9.3, m9-quiz-9.3-interactive |
| 9.4 Students will understand the notion of modeling light photons as qubits and determine some of their basic properties with respect to measurement. | m9-QuantumTheoryAtWork, m9-LightIntensityAndTransmissionProbability,  m9-Conclusions |
| M10 - Basics of Quantum Computing/Cryptography | |
| 10.1 Students will be able to model two level quantum systems using vector and ket representations. | m10-ClassicalBits, m10-Qubits, m10-KetNotation |
| 10.2 Students will understand the notions qubit, amplitude and probability of collapse. | m10-QubitsAndMeasurement, m10-LinearCombinationAndExample, m10-quiz-10.1, m10-quiz-10.1-interactive |
| 10.3 Students will understand the notion of superposition. | m10-Superposition |
| 10.4 Students will be able to change between basis representations for a given qubit. | m10-Basis |
| 10.5 Students will be able to determine if it is a Superposition or Not Superposition | m10-SuperpositionOrNotSuperposition,  m10-quiz-10.2, m10-quiz-10.2-interactive |
| M11 – Basics of Measuring a Qubit | |
| 11.1 Students will understand the basics of measuring a qubit. | m11-MeasuringAQubit |
| 11.2 Students will be able to compute the probabilities of outcomes upon measurement. | m11-MeasuringAQubit , can we break the cell? |
| 11.3 Student will be able to compute transition amplitudes from one state to the other. | m11-TransitionAmplitudes, m11-ComplexQubitTransition, m11-GeneralTransitionAmplitudes, m11-ExampleTransitionAmplitude |
| 11.4 Student will understand the notion of global and local phase and their interpretations. | m11-GlobalAndRelativePhases, m11-Quiz-11.1 |
| M12 – Visualizing a qubit | |
| 12.1 Student will understand the bloch Sphere reprenstation for a qubit. | m12-BlochSphere, m12-BlochSphereContd, m12-BlochSphereContd2 |
| 12.2 Student will be able to simulate bloch Sphere qubit | m12-BlochSphereVisualization, m12-InteractiveBlochSphereSimulation, m12-GeometryOfBlochSphere |
| 12.3 Student will be able to simulate the 2D representation | m12-Simple2DRepresentation, m12-BlochSphere2dVisualization, m12-InteractiveBlochSphere2dSimulation, m12-UnitCircleVisualization, m12-InteractiveUnitCircleSimulation |
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| M13 – General Single – Qubit Measurement | |
| 13.1 Students will understand the theory behind projective measurements. | m13-QuantumMeasurements, m13-ComputingTheProjection |
| 13.2 Students will understand the measurement postulate in quantum mechanics for projective measurements. | m13-ComputingTheProjection, m13-TheProjectionOperators, m13-MeasurementOperatorIdentity, m13-ExampleProjectionOperators, m13-ApplyingProjectionOperators |
| 13.3 Students will be able to compute the projection operators for a basis. | m13-QuantumMeasurementPostulate,  m13-ComputationalBasisMeasurement,  m13-PostMeasurementStates, m13-quiz-13.1 |
| 13.4 Students will be able to calculate the probabilities of outcomes for a given basis using projection operator and determine the final state of the qubit. |  |
| 13.5 Students will understand the density matrix formulation and will be able to apply it for projective measurements. |  |
| M14 – Single-Qubit Gates and Operations | |
| 14.1 Students will understand and will be able to apply common single-qubit operations (gates). | m14-TransformationsOnQubits, m14-SingleQubitTransformations, m14-PauliMatrices, m14-quiz-14.1 |
| 14.2 Students will be able to build sequential quantum circuits for single qubits. | m14-BuildingCircuits, |
| 14.3 Students will be able to compute the effect of given sequential quantum circuit on a qubit. | m14-ComputingCircuitOperation, m14-quiz-14.2 |
| M15 – Multi-qubit Systems | |
| 15.1. Students will represent the state of a multi-qubit system. |  |
| 15.2. Students will be able to construct the basis for a multi-qubit system. |  |
| M16 – Multiple Qubits and Entangled Systems | |
| 16.1. Students will be able to create joint state representations of quantum systems with multiple qubits. | m16-TwoQubitSystems, m16-Measurement, m16-PartialMeasurement, m16-PartialMeasurementExample, m16-quiz-16.1 |
| 16.2. Students will understand the notion of entangled quantum systems. | m16-EntangledSystems, |
| 16.3. Students will be able to perform measurements on joint quantum states. | m16-ReverseQuestionDecomposition,  m16-MeasuringTheBellState, m16-quiz-16.2 |
| 16.4. Students will be able to perform partial-measurements on joint quantum states. |  |
| M17 – The EPR Paradox and CHSH Game | |
| 17.1 Students will understand the significance of EPR pairs and their implications. | m17-EPRParadox, m17-EntanglementAndSeparation, |
| 17.2 Students will understand Bell's inequality and CHSH game that verifies Bell's inequality. | m17-RotationalInvarianceOfBellState,  m17-CHSHInequality, m17-QuantumAdvantageCHSH, m17-CHSHGameStrategy, m17-CHSHGameOutcome |
| M18 – Multi – Qubit Gates and Operations | |
| 18.1. Students will be able to construct multi-qubit gates from single qubit gates. | m18-ComposingSingleQubitOperations,  m18-JointGateRepresentation, m18-JointGateRepresentationConclusion, m18-GateOperationOnJointQubits |
| 18.2. Students will understand the operations of new multi-qubit gates. | m18-TrueMultiQubitGates, m18-TheCNOTGate, m18-CNOTGateExample, m18-CNOTGateXOR |
| 18.3. Students will be able to compute outputs of circuits consisting of multiple qubits. | m18-CNOTUnitaryInverse, m18-CNOTBasisDependency, m18-CNOTForEntanglement, m18-GeneralControlledOperation, m18-CNOTForSwap, m18-OtherMultiQubitGates, m18-UniversalGateSet |