■ Roadmap for Qiskit & Quantum Computing Jupyter Notebook

Module 0: Introduction

- What is quantum computing? (high-level overview)
- Qubit vs classical bit
- Installing Qiskit (pip install qiskit)
- Importing and setting up (from qiskit import * basics)

Module 1: Single-Qubit Foundations

- Creating a qubit & visualizing on Bloch Sphere
- Measurement in computational basis
- Single-qubit gates: Pauli-X, Y, Z, Hadamard, Phase, T, S
- Bloch sphere visualization (plot_bloch_multivector)
- Hands-on: superposition states

Module 2: Multi-Qubit Systems

- Tensor product & multi-qubit state construction
- CNOT gate, Controlled-Z
- Swap gate
- Building simple two-qubit circuits
- Hands-on: Bell state preparation & measurement

Module 3: Entanglement & Quantum Phenomena

- Bell states & their measurement correlations
- GHZ state creation
- Quantum teleportation protocol (step-by-step)
- Superdense coding
- Hands-on experiments with simulation

Module 4: Quantum Algorithms – Foundations

- Deutsch-Jozsa Algorithm
- Bernstein-Vazirani Algorithm
- Grover’s Algorithm (search problem)
- Shor’s Algorithm (integer factorization — toy example)
- Hands-on coding each algorithm

Module 5: Intermediate Algorithms & Applications

- Quantum Fourier Transform (QFT) + applications
- Phase Estimation
- Quantum Approximate Optimization Algorithm (QAOA) — intro
- Variational Quantum Eigensolver (VQE) — chemistry example

- Hands-on: small optimization problem with QAOA

Module 6: Quantum Machine Learning (QML)

- Encoding classical data into quantum states (feature maps)
- Quantum kernels & QSVM (Quantum SVM)
- Hybrid Quantum-Classical Neural Networks (using qiskit-machine-learning)
- Hands-on: Toy classification problem with QSVM

Module 7: Quantum Hardware & Noise

- Qiskit Aer simulator vs. IBMQ real backend
- Noise models (decoherence, gate errors)
- Running circuits on noisy simulators
- Error mitigation techniques (measurement error mitigation, zero-noise extrapolation)
- Hands-on: Compare ideal vs noisy circuit outputs

Module 8: Advanced Topics & Future Directions

- Quantum advantage & current limitations
- Recent breakthroughs (quantum supremacy experiments)
- Quantum cryptography (brief E91/QKD mention)
- Further resources: textbooks, courses, IBM Qiskit resources

■ Suggested Flow for Students

- Start with setup & single-qubit basics → get comfortable coding and visualizing circuits.
- Move to multi-qubit & entanglement → build intuition for why quantum is different.
- Introduce algorithms (Deutsch–Jozsa → Grover → Shor) → see computational advantages.
- Bring in intermediate & variational algorithms (VQE, QAOA) → connect to optimization & chemistry.
- Add QML → modern applications and hybrid workflows.
- Finish with noise, error mitigation, and real hardware → prepare for practical usage.