MASTER TEACHER'S GUIDE

Unit Title: Quantum Teleportation & Dynamic Protocols (Week 4)

This module is the last chapter of introduction to QC of the first month. It synthesizes all previous concepts—state vectors, unitary matrices, and entanglement—into a single, coherent protocol. It proves that quantum states can be transmitted without physically moving the particle, using entanglement as a resource.

Field	**Detail**
Target Audience	**Tier 3 - Undergraduate / Developer Level**
Design Principle	**Protocol Formalism.** Concepts require students to track a 3-qubit state vector through a specific sequence of gates ($CNOT \to H \to$ Measurement → Correction) and mathematically prove the final state matches the initial state.
Learning Progression	**3-Qubit State Prep → Bell Basis Measurement → Conditional Logic (Classical Feed-Forward) → State Reconstruction.**
Duration	**1 Week** (approx. 4×60-90 minute sessions)
Teacher Guidance	Proficiency in 3-qubit tensor products ($2^3 = 8$ dimensions) is helpful, but the focus is on the *logic flow*. Emphasize that "teleportation" destroys the original state (No-Cloning) and requires classical communication (No Faster-Than-Light).

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2. Pedagogical Framework: The Teleportation Engine

This unit uses **Circuit Logic** to implement a physical protocol. The goal is to move students from "static correlations" to "dynamic state transfer."

Focus Area	**Objective (The student will be able to...)**	**Bloom's Level**
Science/Literacy	Explain why teleportation is not "instant" (requires classical bits) and how it respects the **No-Cloning Theorem** (original state is destroyed).	**Understanding, Evaluating**
Mathematics	Logically regroup a 3-qubit state vector $\|q_C q_A q_B\rangle = \|\Psi_{total}\rangle$ to show that after Alice's measurement, Bob's qubit is left in one of four specific states	**Evaluating, Applying**
Computational Logic	Implement the full Teleportation circuit in Qiskit, using **Classical Registers** to store measurement	**Applying, Creating**

	results and **Conditional Gates** (*c_if*) to apply corrections.	

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3. Computational Logic Refinements (Week 4)

A. The Setup: 3-Qubit System

Concept	**Explanation**	**Mathematical Description**
The Cat (q_C)	The unknown state used	$\|\psi\rangle = \alpha\|0\rangle + \beta\|1\rangle$
The Channel (q_A, q_B)	The pre-shared entangled Bell pair that links Alice and Bob.	$\|\Phi^+\rangle = \frac{1}{\sqrt{2}}(\|00\rangle + \|11\rangle)$

B. The Process: Bell Measurement

Concept	**Explanation**	**Mathematical Description**
Basis Change	Alice transforms her two qubits (q_A, q_C)) from the computational basis to the Bell basis.	$H(q_C) \cdot CNOT(q_C, q_A)$
Measurement	Alice measures q_C and q_A, collapsing the system into one of 4 classical outcomes (00, 01, 10, 11).	Measure $\|q_C q_A\rangle$

C. The Correction: Feed-Forward

Concept	**Explanation**	**Mathematical Description**
Classical Bits	The measurement results must be sent to Bob via a classical channel (limit of light speed).	Send bits $\|q_C q_A\rangle$
Correction Gates	Bob applies gates based on the bits to recover $\|\psi\rangle$	

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4. Exemplary Lesson Plan: The Quantum Transporter

Module: Building the Protocol This lesson focuses on the step-by-step construction of the circuit, validating the math at each stage.

Coding Lab: Teleportation

Objective	**Students will build the quantum teleportation circuit in Qiskit, verifying that the state |ψ⟩ disappears from qubit 0 and reappears on qubit 2.**

Required Resources	Python Environment (Jupyter), Tier3W4_coding.ipynb, T4W4_draft.ipynb (Lecture Notes)

Step-by-Step Instructions

Part 1: The Math (Pen & Paper - Lecture Notes)

1. **State Expansion:** Follow the derivation in T4W4_draft.ipynb. Write out the full state $|\psi\rangle \otimes |\Phi^+\rangle$.
2. **Gate Trace:** Apply $CNOT$ then H. Regroup terms to see Bob's state dependence.
3. **Prediction:** Prove that if Alice measures "11", Bob has the state $ZX|\psi\rangle$.

Part 2: The Code (Qiskit Implementation)

1. **Task 1 (Setup):** Initialize a 3-qubit circuit. Prepare a random state on q_0 (or a known one like $|1\rangle\ or\ |+\rangle$). Create a Bell pair on q_1, q_2.
2. **Task 2 (Alice's Box):** Implement the Bell measurement: *qc.cx(0, 1)* then *qc.h(0)*. Measure q_0, q_1 into classical bits.
3. **Task 3 (Bob's Correction):** Use *c_if* commands.
   - *qc.x(2).c_if(cr, 1)* (Apply X if bit is 1)
   - *qc.z(2).c_if(cr, 2)* (Apply Z if bit is 2 - *Note: check bit indexing carefully in Qiskit*)
4. **Verification:** Measure Bob's qubit. If we teleported $|1\rangle$, Bob must measure 1 at 100% of the time. If we teleported $|+\rangle$, Bob must measure $0\ or\ 1$ 50/50.

Part 3: Assessment

- **Quiz Question 3:** What information does Alice send to Bob? (Answer: 2 classical bits).
- **Quiz Question 5:** Why is this not FTL communication? (Answer: Bob needs the classical bits to fix his state).
- **Quiz Question 7:** Which correction is applied for the measurement "10"? (Answer: Z gate).

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5. Resources for Curriculum Implementation (Week 4)

Resource Name	Type	Purpose in Curriculum

T4W4_draft	**Lecture Notes (IPYNB)**	The "Textbook." Contains the formal derivation (LaTeX) of the protocol and the "Regrouping" logic.
Tier3W4_coding	**Lab Notebook (IPYNB)**	The "Workbench." Step-by-step coding tasks to build and run the teleportation circuit.
Tier3W4_quiz	**Quiz (IPYNB)**	**Knowledge Check:** 10 multiple-choice questions focusing on the logic, constraints, and physics of the protocol.

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6. Conclusion and Next Steps

This **Tier 3, Week 4** module completes the foundation of "Quantum Mechanics as Computing." Students have moved from single qubits to entanglement, and now to using entanglement as a functional resource.

Key Takeaway: Quantum information is fungible. It can be transferred between particles using entanglement and classical bits. This is the basis for **Quantum Networking**.

Next Steps: Week 5 will pivot to **Noise & Decoherence**. Now that we have built perfect circuits, we must learn why they break. We will introduce the **Density Matrix** to model mixed states and errors.