GHOST GUARD · Teacher guide

A quantum error-correction game for grades 6–8 · 45 minutes · groups of three · unplugged or on screen (GhostGuard_Offline.html)

The big idea. Qubits are fragile, but you cannot protect one by copying it or by looking at it. Instead the information is spread across three coins and the Guardian asks only "do these two coins match?" questions. The answers say where an error is and nothing about the secret. This is how real quantum computers fight noise; in 2024 Google showed a logical qubit that lasted 2.4× longer than its best physical qubit by using this idea at scale.

Learning objectives

#	Students can…
LO1	name two kinds of quantum error: a flip (HEADS ↔ TAILS) and a sign error (green ↔ red chips);
LO2	explain that the ghost is one pattern across three coins, not three copies (no-cloning);
LO3	explain why the Guardian checks parities and never peeks (measurement collapses superposition);
LO4	use the check table to undo one flip, and explain why two flips between checks fool it;
LO5	use the Noise Lab to show the threshold, and that a flip guard cannot see sign errors.

Lesson flow

Min	Activity	Teacher moves
0–5	Hook	"Google made a qubit last longer by using more fragile qubits. How?"
5–10	Level 0 · classical message (whole class)	You are Keeper. One row HHH, flip a coin, let a student peek and vote by majority. Repetition works for ordinary bits.
10–15	Build a ghost (projector, Ghost Box lab)	Two rows with chips. Show Flip (both rows), Check (same answer in both rows), and Peek (one row vanishes).
15–32	Level 1 duels	Groups of three: Guardian, Gremlin, Keeper. Rotate after every game. Tally Guardian wins on the board.
32–38	Level 2 · the Sign Gremlin	Swap one Calm for the Sign card. Ask: did any check notice? Why not?
38–45	Debrief + exit ticket	Noise Lab on the projector: move the flip slider past 50%; then set flips to 0 and raise the sign slider.

Rules in one minute

Seven nights. Guardian hand: 3 Check + 4 Rest. Gremlin hand: 2 Flip + 5 Calm. Each night both place a card face-down; the Keeper applies the Gremlin card behind the folder. Flip k turns coin k over in both rows. On Check the Keeper says only "coins 1 & 2 match / don't match; coins 2 & 3 match / don't match", and the Guardian turns the odd coin out (check table). After night 7 there is a free final check; then the box opens. Same chips, colours and rows → Guardian wins. Peek is allowed, but the ghost collapses to one row (chance ∝ chips², d10) and the Gremlin wins.

Coins 1 & 2	Coins 2 & 3	Turn
match	match	nothing
don't match	match	coin 1
don't match	don't match	coin 2
match	don't match	coin 3

Balance. With best play by both sides each wins exactly half the games (solved exactly). One more Check card makes it 67% for the Guardian; one fewer makes it 33%. Beginners favour the Guardian (≈83% with random play); Gremlins improve once they learn to stack two Flips on different coins inside one gap between checks. Level 2 is deliberately unwinnable for the Guardian.

What each piece means

In the game	In a quantum computer
HHH row and TTT row with chips	one logical qubit $a\|000\rangle + b\|111\rangle$ in the 3-qubit bit-flip code; chips = amplitudes, colour = sign
Flip k	bit-flip error, Pauli X on qubit k

In the game	In a quantum computer
Sign k	phase error, Pauli Z on qubit k
Keeper's "match?" answers	stabiliser (parity) measurements Z_1Z_2 and Z_2Z_3: the same on every branch
Check table	syndrome decoding (majority vote)
Peek + d10 by chips²	measurement and the Born rule; collapse
Two flips → wrong fix → rows swap	logical error: weight-2 error decoded as weight-1
Sign card goes unseen	this code cannot detect Z errors; Shor's 9-qubit code and surface codes check both kinds

Common misconceptions to listen for

Student says…	Ask…
"Just make three copies as a backup."	What would three copies of a two-row ghost look like? (eight rows; and you would have to look to copy it)
"I have to look to find the error."	Did the Keeper ever need to tell you the chips to tell you which coin was odd?
"Errors only flip 0 and 1."	What did the Sign card change, and did the coins move?
"More coins is always safer."	Noise Lab: what happens above 50%? With sign errors, is 5 coins better than 1?
"Peeking just shows what was already there."	Where did the other row's chips go?

Exit ticket with answers

Question	Answer
1. The Keeper says "1 & 2 don't match, 2 & 3 don't match". Which coin do you turn?	coin 2
2. Why may the Guardian never look at a coin?	looking makes the ghost pick one row; the other row and its chips are lost
3. Coins 1 and 3 were both flipped before a check. What happens?	the table says coin 2; turning it makes HHH ↔ TTT, so the rows swap: Gremlin wins
4. True or false: five coins always protect better than three.	false: only when noise is below the threshold, and never against sign errors
5. Name the two kinds of quantum error in the game.	flip (bit-flip, X) and sign (phase, Z)

Honest simplifications

Real parity checks use extra helper qubits and can themselves fail, so real thresholds are near 1%, not 50%. Real amplitudes can be complex numbers; the game needs only positive and negative ones. The Keeper knows the secret only because they prepared it; nature never shows it to anyone. Sources: Shor 1995 (Phys. Rev. A 52, R2493); Devitt et al. 2013 (Rep. Prog. Phys. 76, 076001); Google Quantum AI 2024 (Nature, doi:10.1038/s41586-024-08449-y). Design rationale and literature survey: qgames_survey.md.