Michael Raymer and Margaret Kyser

THE BELL GAME:
Beating the Odds With Quantum Entanglement

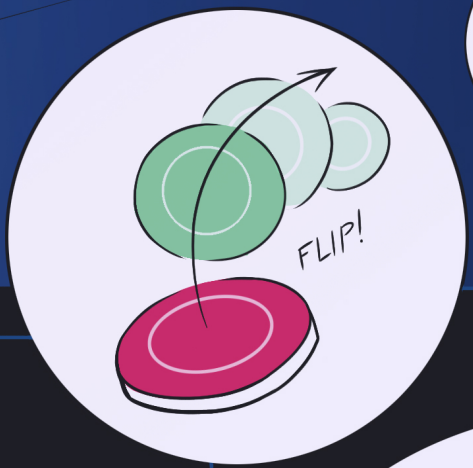
The University of Oregon
Science and Comics Fellowship Program

Celebrating the 2022 Nobel Prize in Physics


ROOM 1
ROOM 2
SCREEN
Welcome to Bell's Casino!
Today we're playing the Bell Game.
* YOU ARE HERE
Earn money and impress your friends!
1
2
Here are the rules...
HOST
People from the audience will come up in pairs. Behind me are two isolation rooms...
Each player will go to Room 1 or Room 2, which each have a gambling machine.
The machines each have two levers, one Red and one Green, that you can pull up or down.
THE BELL GAME
RESULTS

Each player will pay a $1 entry fee ($2 between the two players), and get four tries.

We'll each flip a coin indicating which lever, Red or Green, the players will pull. Each player chooses whether to pull up or down, though.



Also – no communication is possible between the two players or between us, the hosts. However, players are free to strategize together before going into their separate game rooms.

They can also carry a notebook or other device with them, as long as their tools don't allow any outside communication.

Players must pull up or down roughly half the time, but the sequence can be anything – including a coordinated sequence planned before the game begins.

3. If both hosts indicate to pull the Gre
both pull Up or both pull Down, the

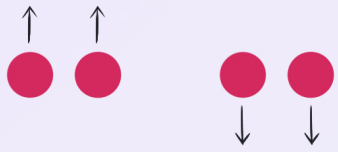
The scoring rules for winning or losing points are shown on the screen behind us.

1

2

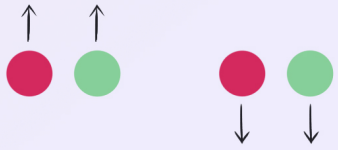
SCORING RULES

1. If both hosts indicate to pull the Red levers, and the players both pull Up or both pull Down, they win one point ($1)



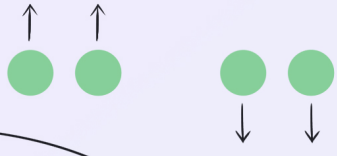
If they pull different, they lose a point (-$1)

2. If the hosts indicate to pull opposite-color levers, and the players both pull Up or both pull Down, they win one point ($1)



If they pull different, they lose a point (-$1)

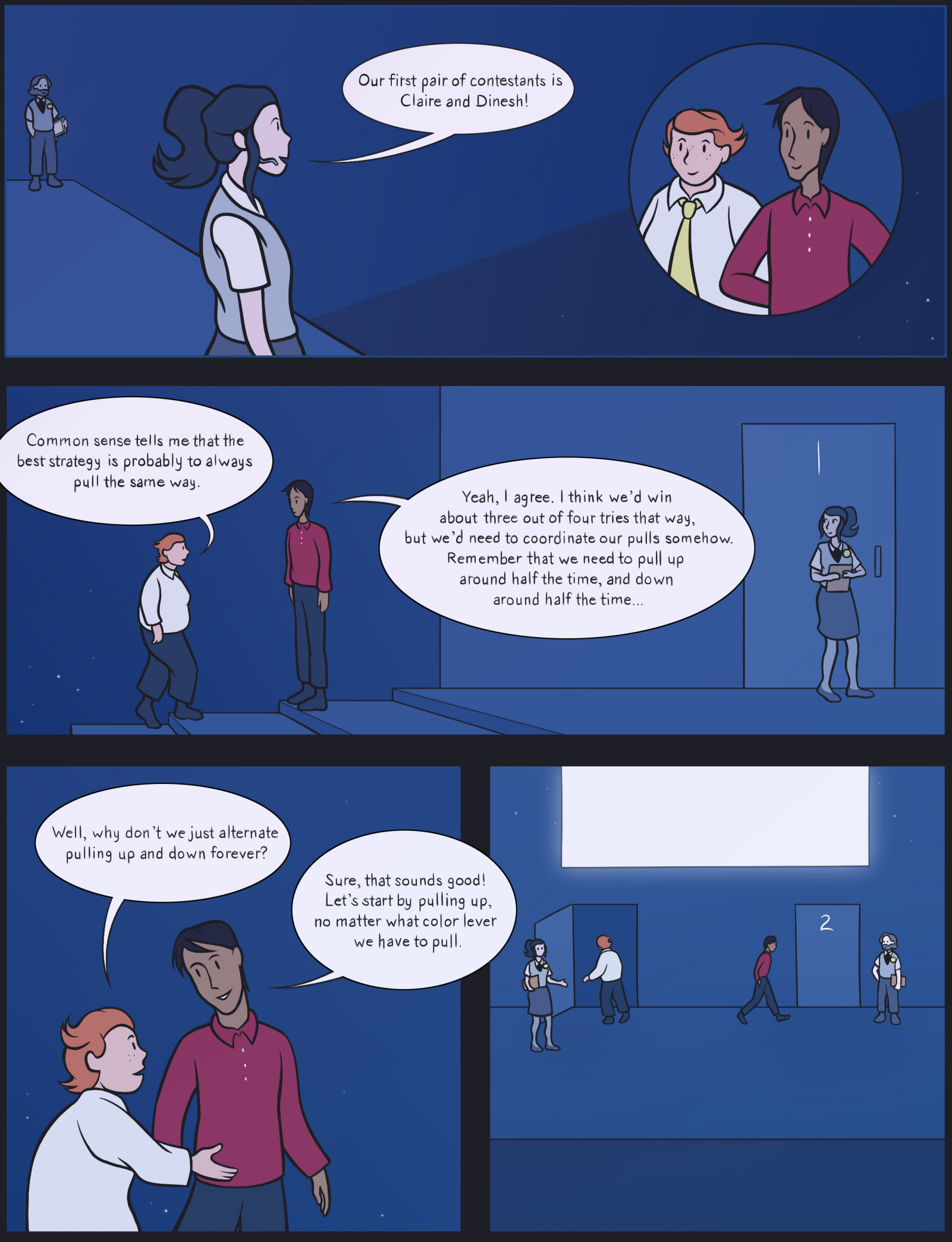
3. If both hosts indicate to pull the Green levers, and the players both pull Up or both pull Down, they lose one point (-$1)

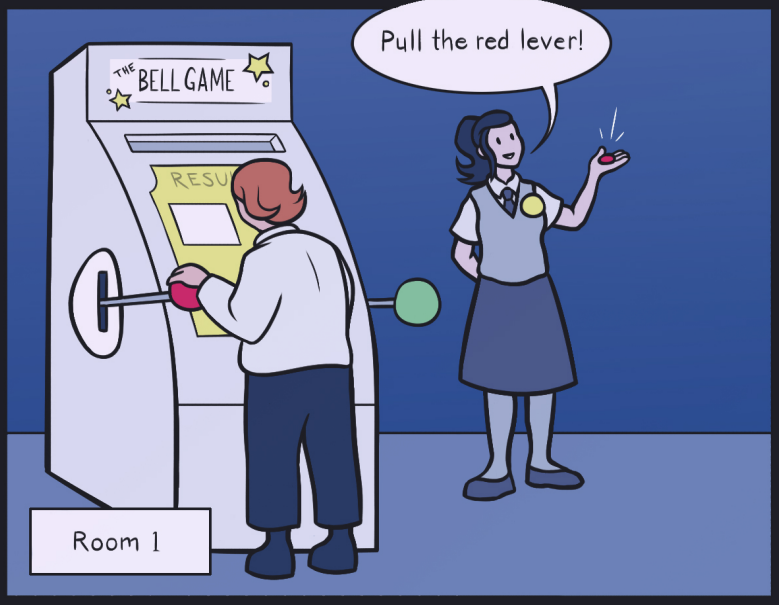


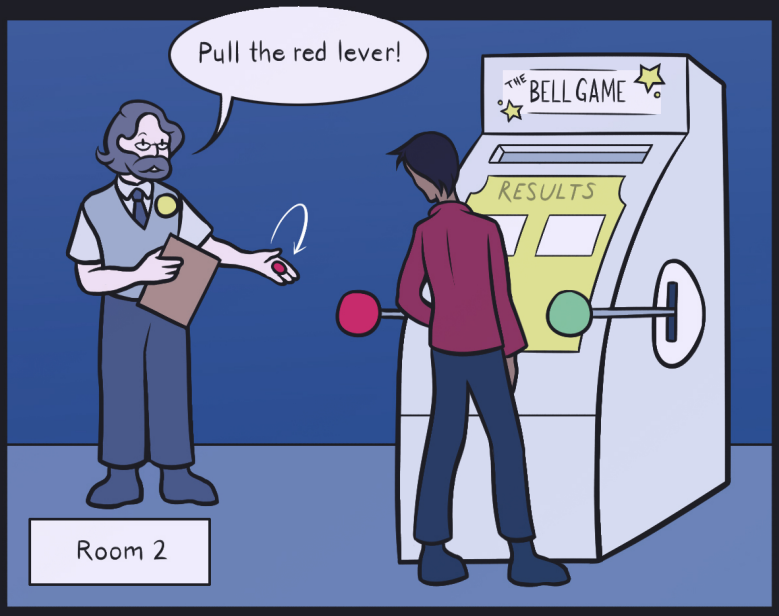
If they pull different, they win a point ($1)

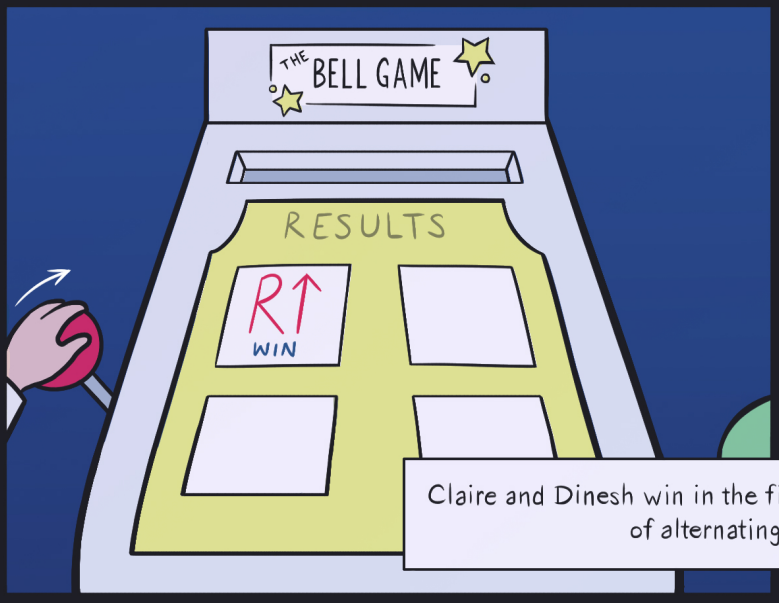
After each set of four tries, the players' sequences of ups and downs will be sent to our central computer, which tallies up the net score and announces the winnings or losses for that set.

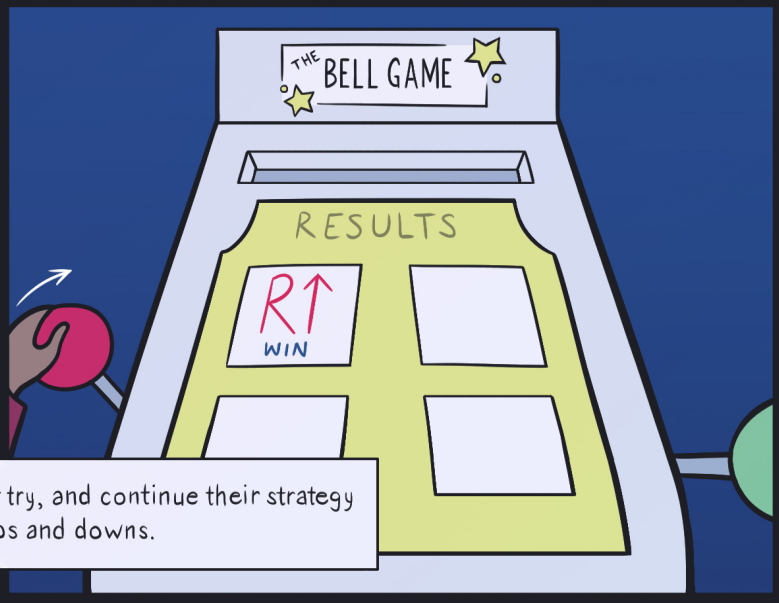
This process happens 99 more times, for a total of 100 four-try sets.


Our first pair of contestants is Claire and Dinesh!
Common sense tells me that the best strategy is probably to always pull the same way.
Yeah, I agree. I think we'd win about three out of four tries that way, but we'd need to coordinate our pulls somehow. Remember that we need to pull up around half the time, and down around half the time...
Well, why don't we just alternate pulling up and down forever?
Sure, that sounds good! Let's start by pulling up, no matter what color lever we have to pull.
2









Claire and Dinesh win in the first try, and continue their strategy of alternating ups and downs.

After paying $2 for four tries, they only manage to win the same amount back, breaking even.

Although they win each try in the following four tries, over 100 sets it becomes clear that on average they break even rather than win more money.

TRY	CLAIRE	FEE ($)	SCORE ($)	NET ($)	DINESH
1	R↑		1		R↑
2	R↓		1		G↓
3	G↑		-1		G↑
4	R↓		1		G↓
		-2	2	0	
1	G↑		1		R↑
2	G↓		1		R↓
3	R↑		1		G↑
4	R↓		1		R↓
		-2	4	+2	
1					
2					
3					

At last, the two leave their isolation rooms and return to the crowd.

There has to be a better strategy to win more.

Hmm...

Actually, the more I think about it, I'm pretty sure there is no better pre-planned strategy. Let's write out other possibilities...

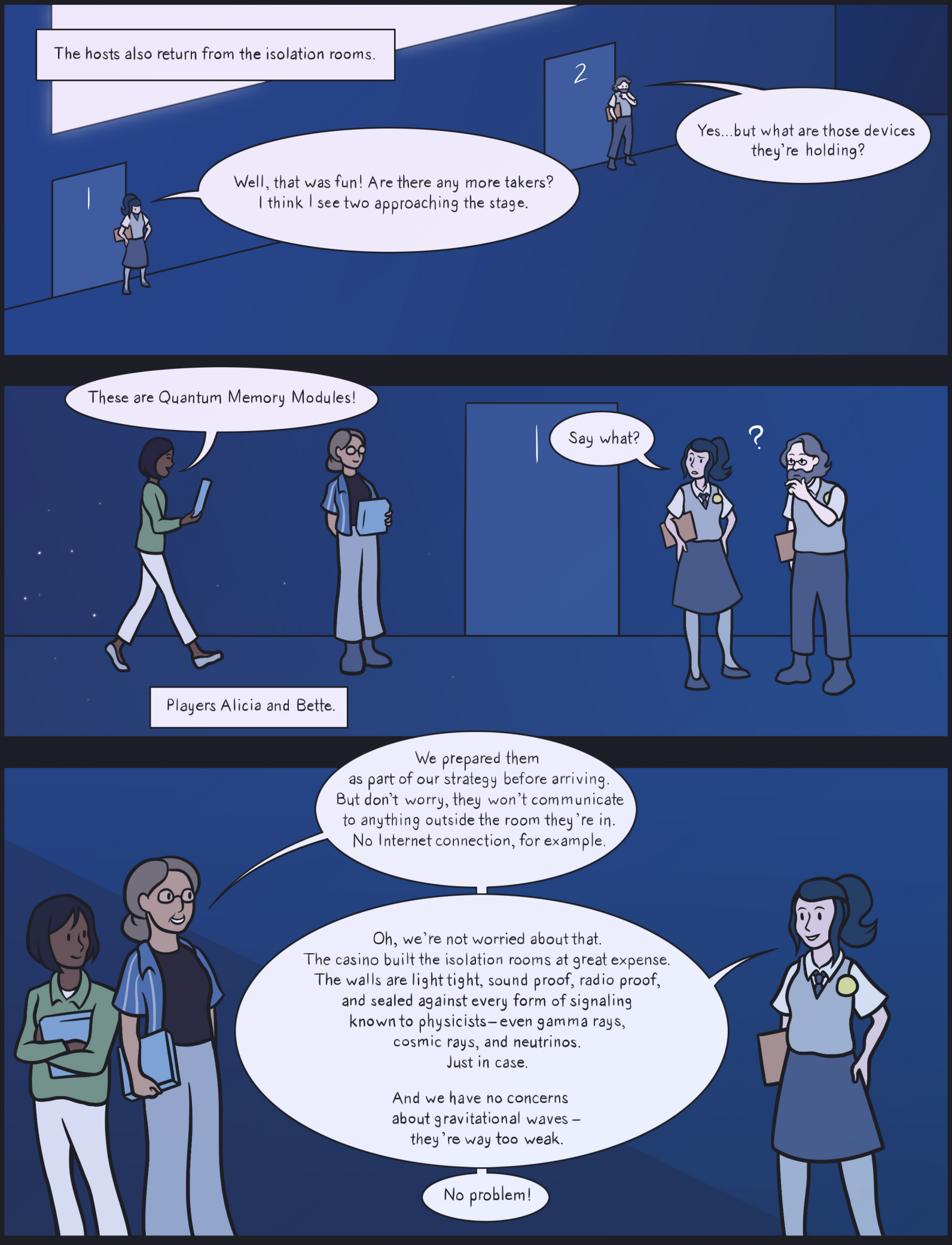
By only pulling the same like we did, players will typically break even. It'd turn out the same way on average even after hundreds or thousands of tries.

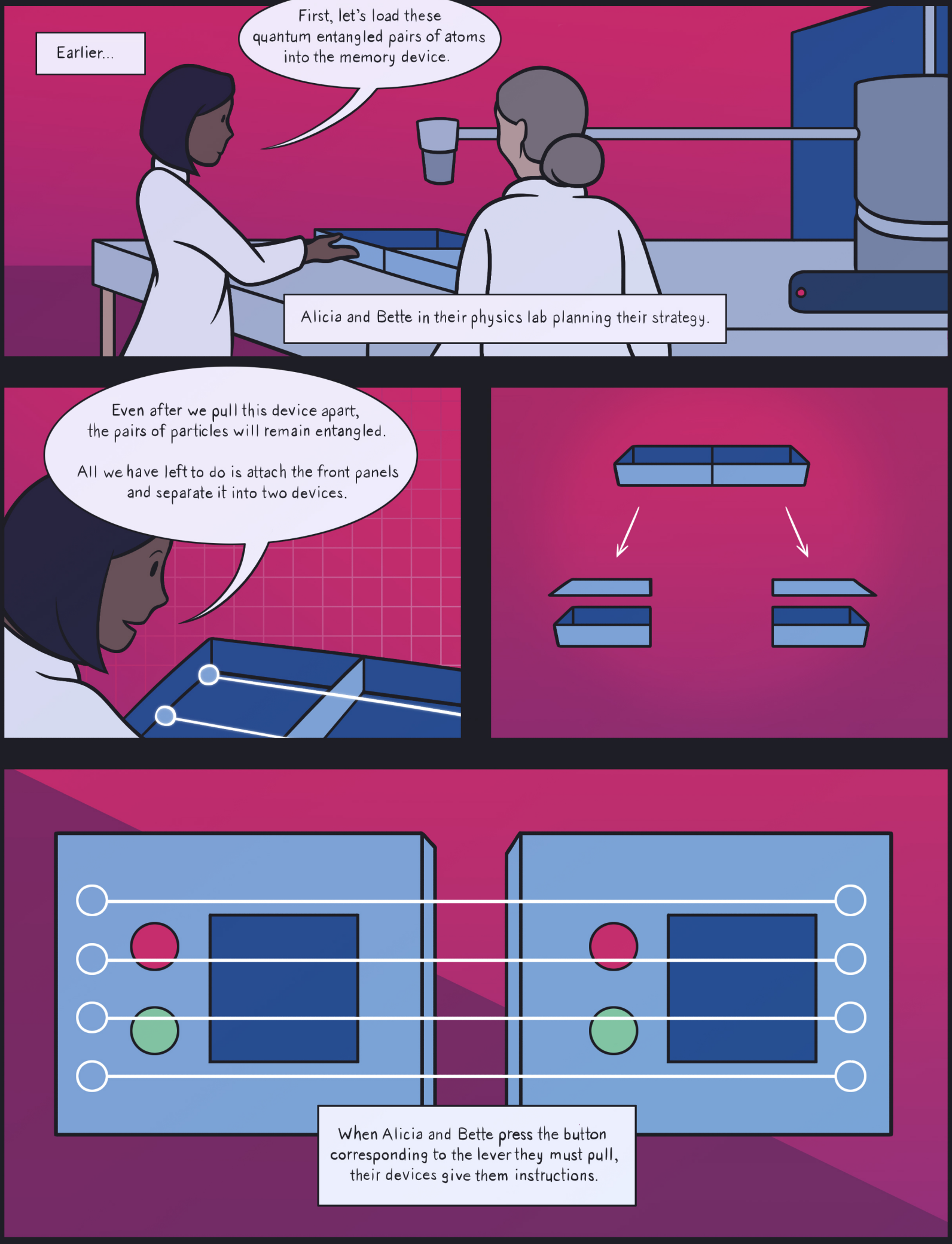
I see...after paying the fee of $2 for four tries, players can only win an average of $2 back, so the game is pointless.

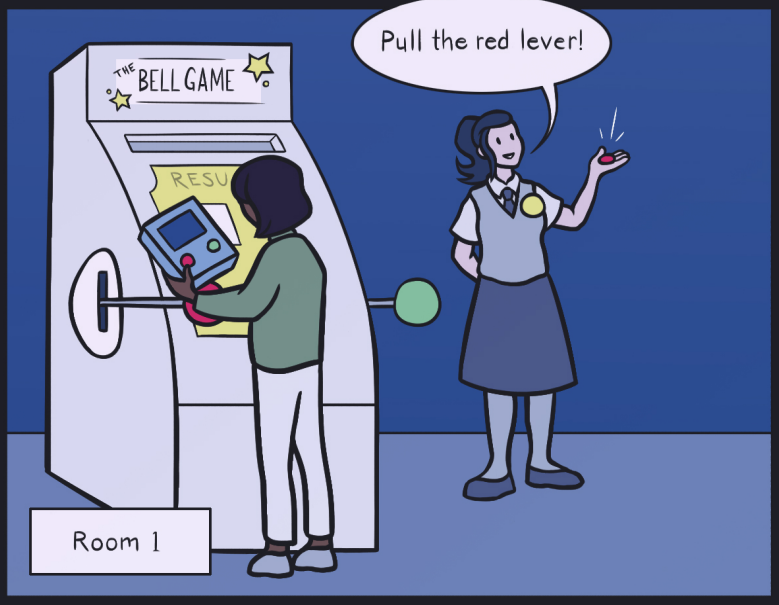
Yeah, and always pulling in the opposite direction would be even worse. We would have lost money that way.

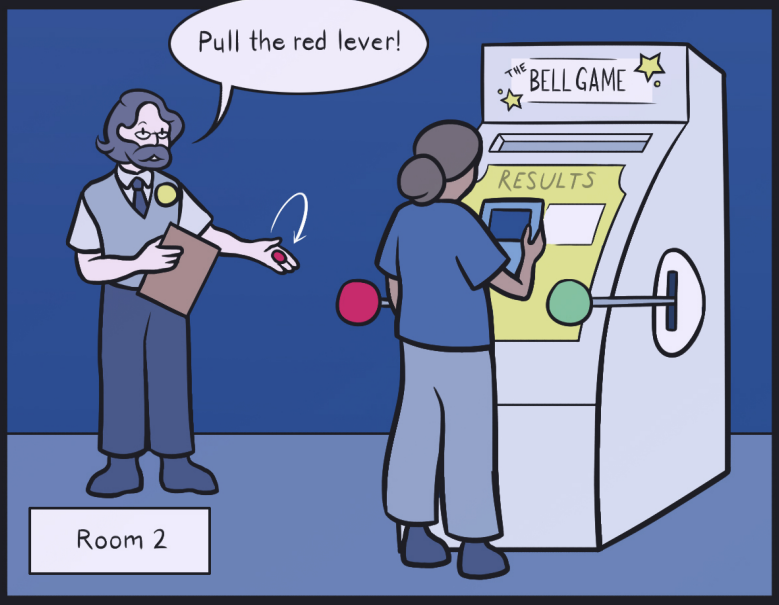
Opposite pulls

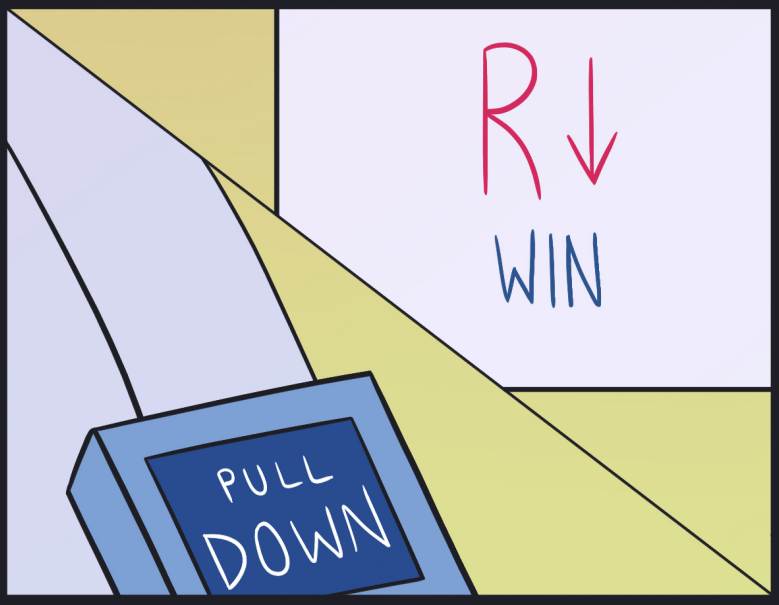
TRY	CLAIRE	FEE ($)	SCORE ($)	NET ($)	DINESH
1	R↑		-1		R↓
2	R↑		-1		G↓
3	G↑		1		G↓
4	R↑		-1		G↓
		-2	-2	-4	
1	G↑		-1		R↓
2	G↑		-1		R↓
3	R↑		-1		G↓
4	R↑		-1		R↓
		-2	-4	-6	

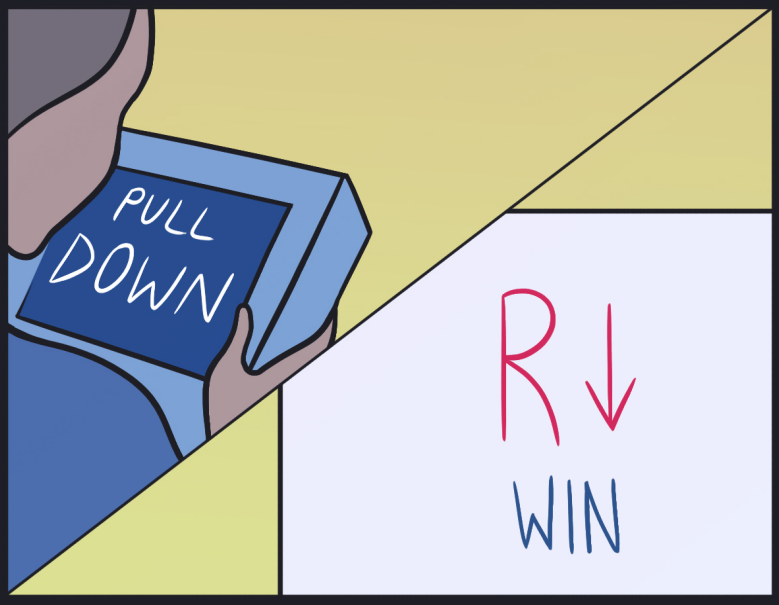

The hosts also return from the isolation rooms.
1
2
Well, that was fun! Are there any more takers? I think I see two approaching the stage.
Yes...but what are those devices they're holding?
These are Quantum Memory Modules!
Say what?
?
Players Alicia and Bette.
We prepared them as part of our strategy before arriving. But don't worry, they won't communicate to anything outside the room they're in. No Internet connection, for example.
Oh, we're not worried about that. The casino built the isolation rooms at great expense. The walls are light tight, sound proof, radio proof, and sealed against every form of signaling known to physicists—even gamma rays, cosmic rays, and neutrinos. Just in case.
And we have no concerns about gravitational waves—they're way too weak.
No problem!


Earlier...
First, let's load these quantum entangled pairs of atoms into the memory device.
Alicia and Bette in their physics lab planning their strategy.
Even after we pull this device apart, the pairs of particles will remain entangled.
All we have left to do is attach the front panels and separate it into two devices.
When Alicia and Bette press the button corresponding to the lever they must pull, their devices give them instructions.





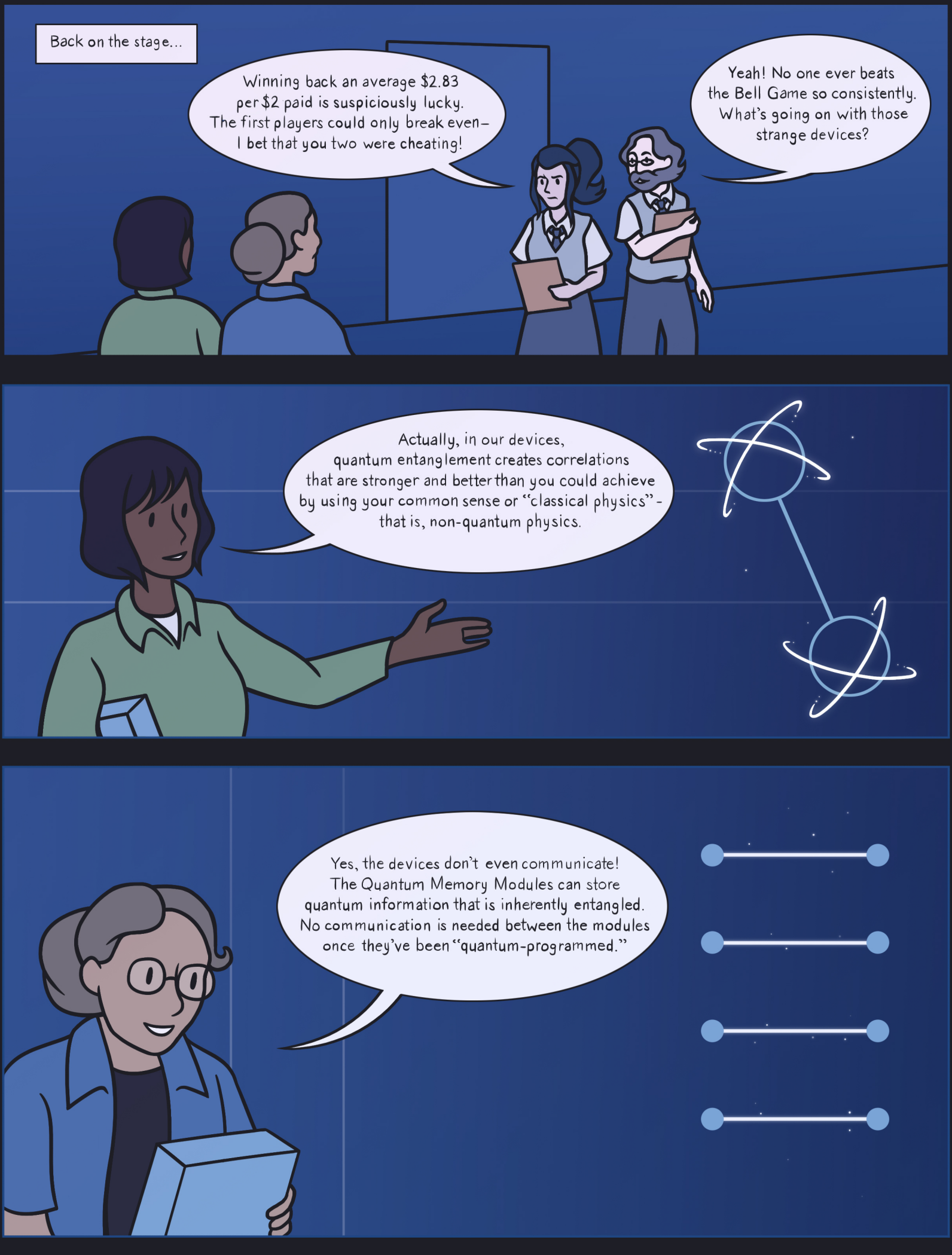


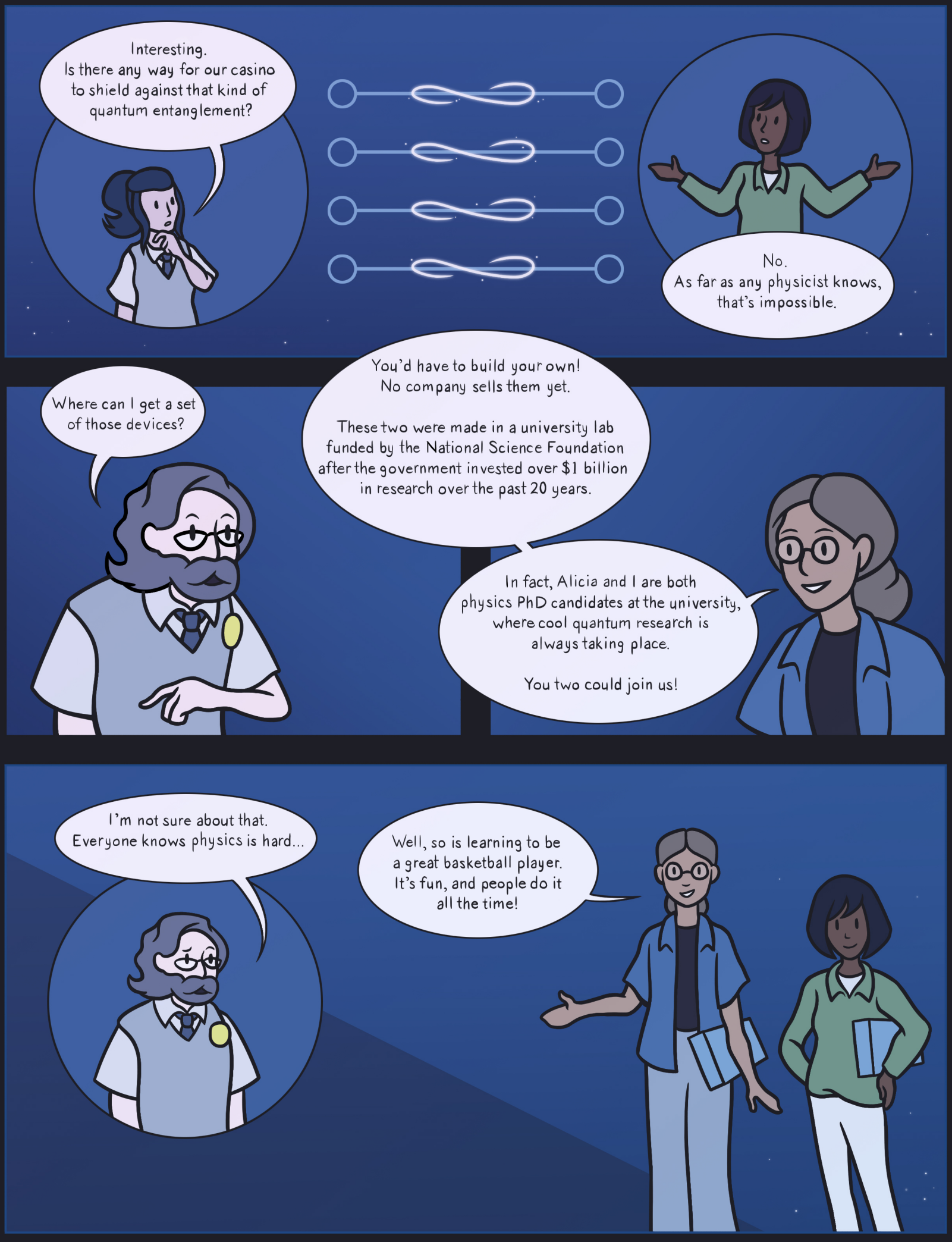


Using their Quantum Memory Modules,
Alicia and Bette win whenever possible.

They win back an average $2.83 for every $2 paid,
or net winnings of $0.83 for each set of four tries.

After 100 sets of four tries, they win $83!


Back on the stage...
Winning back an average $2.83 per $2 paid is suspiciously lucky. The first players could only break even– I bet that you two were cheating!
Yeah! No one ever beats the Bell Game so consistently. What's going on with those strange devices?
Actually, in our devices, quantum entanglement creates correlations that are stronger and better than you could achieve by using your common sense or "classical physics" - that is, non-quantum physics.
Yes, the devices don't even communicate! The Quantum Memory Modules can store quantum information that is inherently entangled. No communication is needed between the modules once they've been "quantum-programmed."


Interesting.
Is there any way for our casino to shield against that kind of quantum entanglement?
No.
As far as any physicist knows, that's impossible.
Where can I get a set of those devices?
You'd have to build your own!
No company sells them yet.
These two were made in a university lab funded by the National Science Foundation after the government invested over $1 billion in research over the past 20 years.
In fact, Alicia and I are both physics PhD candidates at the university, where cool quantum research is always taking place.
You two could join us!
I'm not sure about that.
Everyone knows physics is hard...
Well, so is learning to be a great basketball player.
It's fun, and people do it all the time!

Dear Reader,

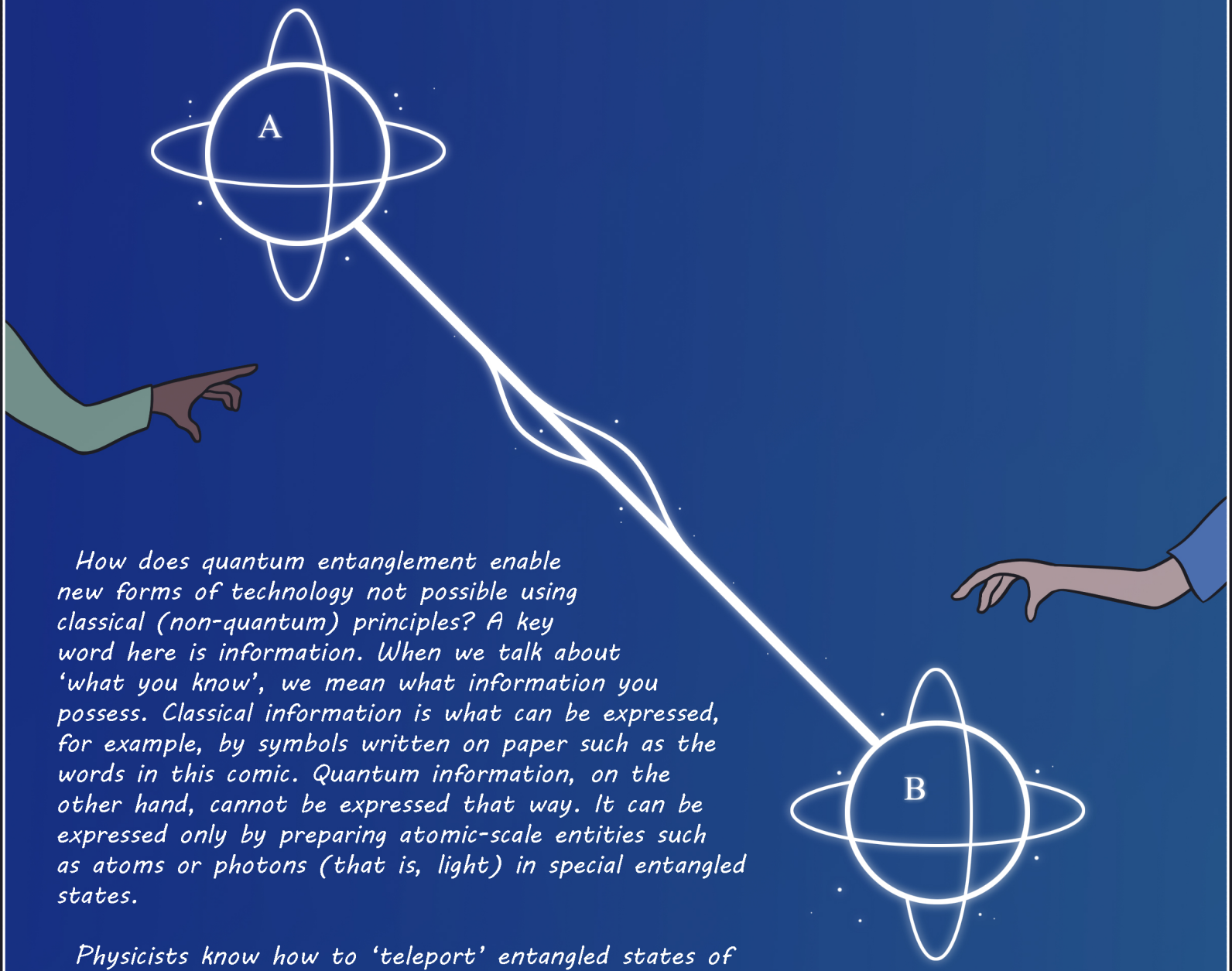
You're probably wondering what was in the hand-held devices Alicia and Bette carried into the rooms that allowed them to win the Bell Game. Is the story science fiction? No! The story could happen exactly as presented, with the exception that we don't yet have portable quantum memory devices available. Quantum memory devices do exist now in quantum physics labs around the world, but they are large, bulky, and not portable. Scientists think it's only a matter of time before miniaturized versions become available.

But, you might ask, what is an entangled state and how does it allow Alicia and Bette to win the game? And do the devices have to be operating by quantum physics principles? Why not two preprogrammed conventional calculators, each having the proper set of instructions that Alicia and Bette are to follow in deciding to pull a lever up or down?

Physicists know that, according to the theory of quantum mechanics, no such devices can be made without controlling matter at the quantum (that is, atomic) level. A conventional calculator (or your phone) stores only conventional (classical) bits of information: 0 or 1. Entanglement of such bits is impossible. Yet at the quantum level, where bits can be stored in single atoms, entanglement is possible. We call such quantum bits qubits. A single qubit can store both possibilities 0 and 1 simultaneously. More importantly, two qubits can be prepared in an entangled state (as Alicia and Bette did in their lab before playing the game) such that, for example, if their values (0 or 1) are read, they will both be 0 or both be 1, even though the outcomes are random with 50/50 probabilities.

That situation is not the same as Claire and Dinesh deciding their strategy with prearranged lists of instructions to always pull up or down together. In the case of entangled qubit instructions, the decisions to pull up or down are not prearranged; the instructions are created spontaneously when needed and are seemingly random. When the players are told by the hosts which lever to pull, each player enters that information into their device and the devices pop up with instructions for which way to pull. In every case the players sometimes win and sometimes lose. Now, though, their overall chance of winning each try is around 85%, instead of 50% as it was in the conventional scenario. For every four tries costing $2, they win around $2.83 on average.

The quantum devices allow Alicia and Bette to beat the conventional odds by using entanglement. It seems like a magic trick because it appears as though the devices "know" what is going on in the other room, even with no possible communication between them. However, it really can work as described in the story using quantum physics and quantum engineering. This type of entanglement has been confirmed by physics experiments carried out in many laboratories.



How does quantum entanglement enable new forms of technology not possible using classical (non-quantum) principles? A key word here is information. When we talk about 'what you know', we mean what information you possess. Classical information is what can be expressed, for example, by symbols written on paper such as the words in this comic. Quantum information, on the other hand, cannot be expressed that way. It can be expressed only by preparing atomic-scale entities such as atoms or photons (that is, light) in special entangled states.

Physicists know how to 'teleport' entangled states of one set of objects to another set of objects. This doesn't mean they transport the objects themselves — only the information about the objects is teleported. This kind of information transfer is what quantum computers will need to communicate among themselves and is what gives quantum computers a big advantage over ordinary computers for solving certain kinds of mathematics problems.

The 2022 Nobel Prize honored the physicists who verified that quantum entanglement is actually an aspect of the world we live in and opened the door for many new applications to come.

If you'd like to dive deeper into the ideas of quantum entanglement and how it works in the Bell Game, in cryptography, and in computing, you can learn all about it in a book by one of this comic's authors, Michael Raymer: Quantum Physics: What Everyone Needs to Know. Find the book by scanning the QR code.

Another accessible book which describes the Bell Game is Nicolas Gisin's Quantum Chance: Nonlocality, Teleportation and Other Quantum Marvels.

Michael Raymer's book:

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The 2022 Nobel Prize in Physics was awarded to Alain Aspect, John Clauser, and Anton Zeilinger for experiments showing that quantum entanglement across macroscopic distances can create measurement correlations that defy any 'classical-physics' description. Mysteriously, such correlations exist without any physical, non-local interaction mechanism, yet they are the basis of the newly emerging possibilities offered by quantum technologies.

John Clauser

"It was the quest
to understand quantum mechanics
that has kept me going
all this time."

Anton Zeilinger

"Quantum teleportation
is a child of science fiction in a sense.
The mistake they made is they thought
in order to teleport somebody you have
to teleport the substance
you are made of.

We found it's enough
to transport the quantum state -
the embodiment of all information which characterizes you.
It's a means of transporting the output of one
quantum computer to the input of another
quantum computer."

Alain Aspect

"I'm sure I am not good
at going to applications myself.
But I explained what I have been doing as basic science,
and people around listen to it and say -
Oh, we could use that
for something."

Quotes from Nobel Minds 2022:
https://www.youtube.com/watch?v=LutI8YqJkqM