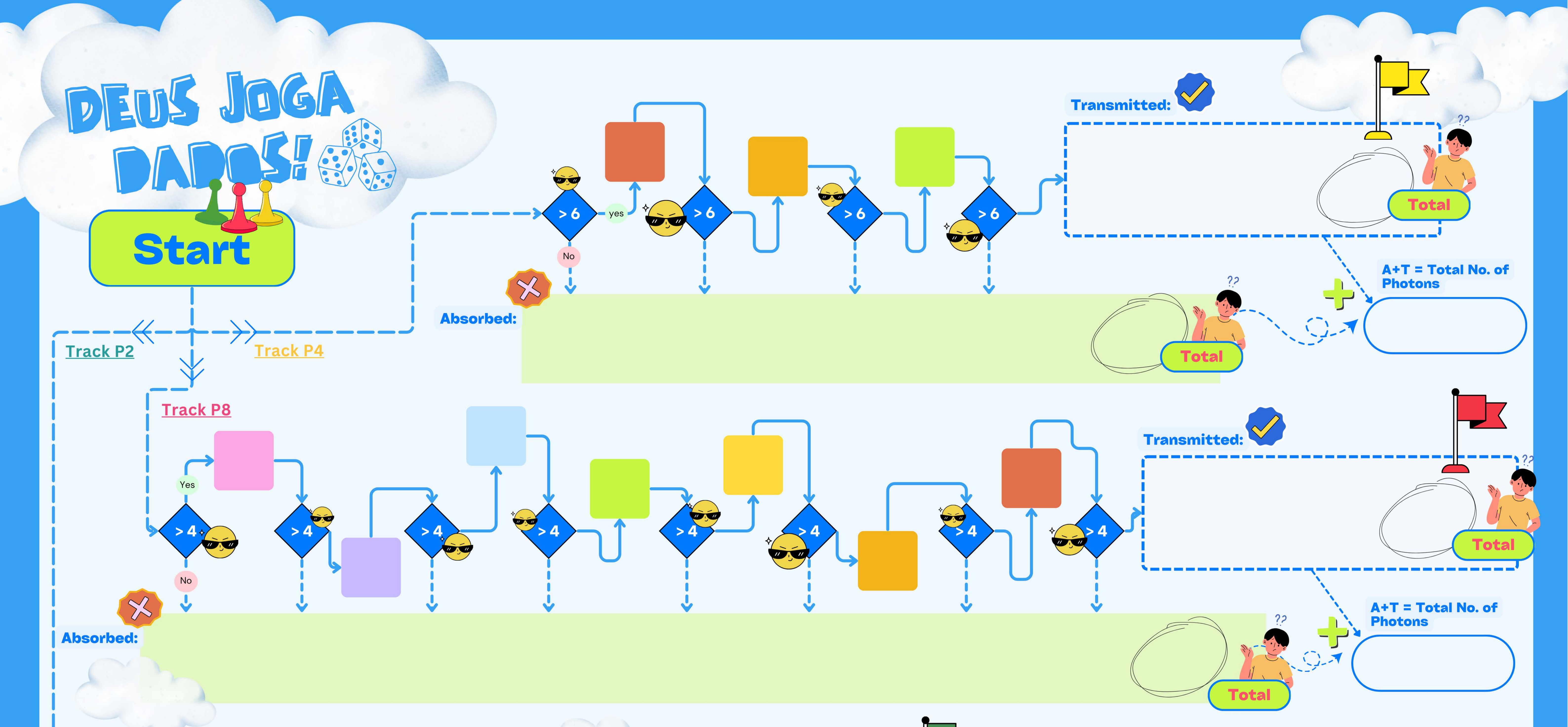


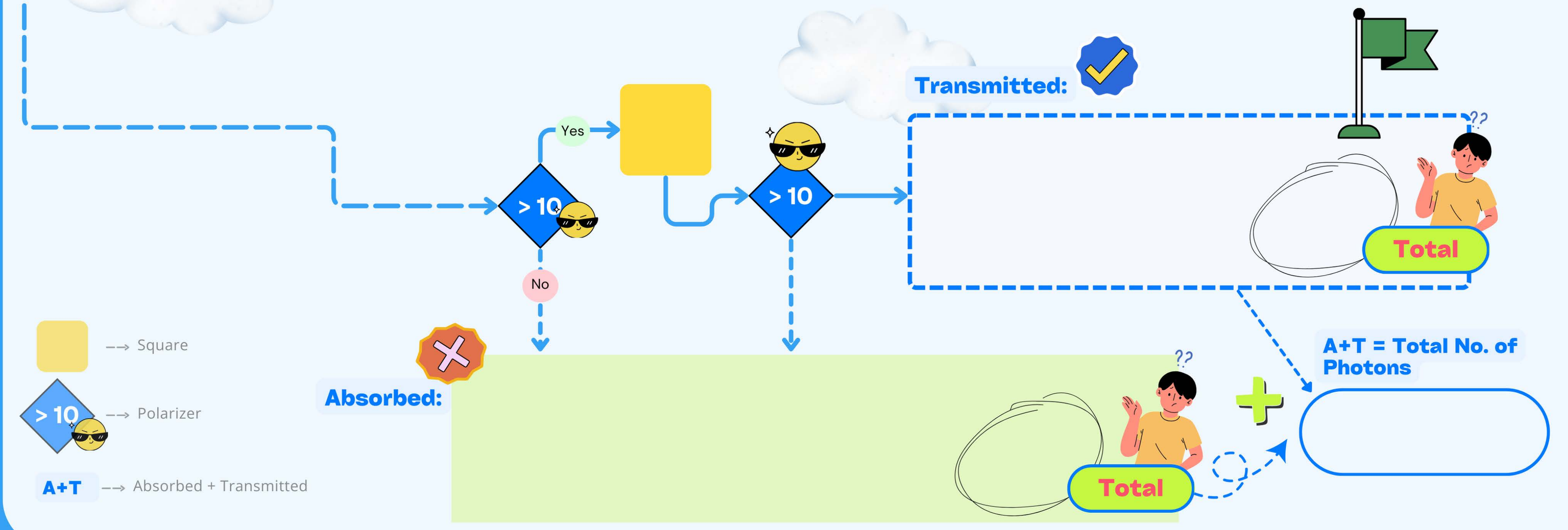


***Does God play dice?***

This game is collaborative between a certain number of participants, although it is played individually in turns, and aims to demonstrate the random nature of quantum physics. The more participants who play, the better the statistics will be and closer to the expected physical result.

**1)** Initially, each player places their pawn(s) on the starting square; these pawns represent photons with a certain state of polarisation, and each follows a pre-selected colour track.
**2)** After the three dice have been thrown, the sum of the dice is taken. Depending on the value of this value, the pawns advance simultaneously to the next square (◙) on their lanes if the transmission condition (♦) is met; otherwise they are rejected and go to the square where the absorbed pawns perish.
**3)** The transmission criterion is equivalent to the angle of the crossed 'polarizer': 45° between polarisers corresponds to dividing the right angle (90°) by 2, i.e. we have half the odds, so it adds up to 10. If we have 4 polarisers dividing the right angle, we have 1/4 of the probability, i.e. 6. If we have 8 polarisers, the angle between them is 11.25° and the corresponding probability is 4.
**4)** It is noted how many photon pawns make it to the end of each lane.
**5)** After reaching a finishing square, each photon pawn is repositioned on the starting square and continues its game.
**6)** The ratio between the pawns that have crossed the cascade of 'polarisers' and the total for each route can be checked in a similar elab experiment and analysed according to its quantum explanation.

***3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18*** → *Possible Sums*

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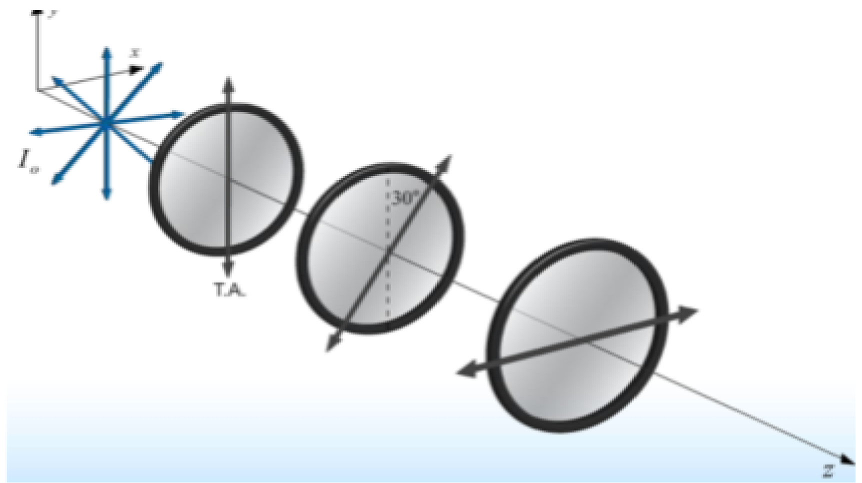
# God play dice!

In one of Einstein's letters to Max Bohr, two renowned scientists, Einstein wonders: ‘Quantum theory produces a good result, but it hardly brings us any closer to the secret of the Creator. I am in any case convinced that He does not play dice.’ *sic*.
But is the random (stochastic) process of quantum physics really like that? Apparently when we play dice or roulette we know that ONE roll is completely random, but for LARGE NUMBERS we can predict an average value: for example, playing with two dice, if someone always bets on 7, after many rolls they will win over any other bet!
That's why Einstein believed that ‘Everything is determined, both the beginning and the end, by forces over which we have no control...
We all dance to a mysterious melody, intoned from a distance by an invisible “player”.
In other words, even if we accept the random nature of quantum mechanics, physics is determined at some point...
This game is designed to show you how close physics is to a game of dice!

# Game foundations

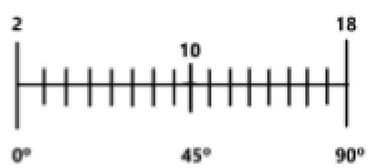
Light is both wave-like and a quantum particle in nature, as we can describe the physical phenomena of light by interpreting it as a collection of particles.
This game is based on an important characteristic of light, its polarisation.
Polarisers are materials that only allow each photon to pass through a certain state of polarisation: if the photon is in a combination of two states, for example horizontal and vertical, and we see it passing through a polariser, then it is defined as having the polarisation of that polariser's orientation. When thinking about a single photon, it's interesting to note that this passage through the polariser has a certain probability of occurring depending on the angle of the initial polarisation of the light with the polariser's axis. This probability is shown to be equal to the square of the cosine of this angle.
In fact, if the polariser is at 90º this probability is zero, i.e. all the light is blocked, and if it is aligned at 0º it is 100%, i.e. all the light gets through. For intermediate values, in this game we'll make a proportionality between the angle and the values of the sum of three dice that we know vary between 3 and 18. As our dice don't start from zero, we'll associate the value 2 with zero and 18 with 90º.
So, if the photon encounters a polariser aligned with its state, its angle is 0º and, when you roll the dice, you always get a value greater than 2, so the photon is never absorbed by the polariser, i.e. it always passes through it. On the other hand, if it's at 90º, any roll of the dice will never be higher than 18 and consequently it will never get through the polariser.
In an intermediate range of values, we'll make the corresponding proportionality, i.e. a value of 45º will correspond to obtaining a throw of more than 10. For lower angles, the requirement is lower, i.e. 22.5º will be 6 and 11.25º will be 4.




With three polarisers, the probability of a photon emerging is 25%, since: (i) the first polariser defines the vertically polarised state; (ii) when passing through the second, the probability of passing is 50%, and if the photon manages to pass—assuming the polarisation of the second polariser—this means that when it reaches the third, there is again a 50% chance of passing through. That totals 25% at the end of the optical path (0.5 × 0.5 = 0.25).

## The optical path

In this game we have three paths or lanes (P2, P4 and P8) that cross 2, 4 or 8 polarisers. We also consider that the polarisers divide the right angle into equal parts, for example, on track P2 they are positioned at 45º to each other and on track P8 each one is 11.25º away from its antecedent. This is why the probability of crossing varies according to the figure below. On each polariser, the photon pawn has to throw the dice to cross it and try to reach the finish of its lane... or be rejected, which is equivalent to being absorbed into the polariser! Each pawn represents a photon traveling in space and crossing a set of polarisers, each polarizer being described as the condition of passage on the board (♦). Three photon pawns set off simultaneously at the start of the game but then travel independently, creating their own statistics, which are calculated at the end of the game. When they reach a target, they are repositioned in the start and go on a new journey as a reborn photon.




Relationship between the angles of light polarisation and the threshold value of the sum of the data. For example, with an angle of 22.5 º, the photon is transmitted if that sum is greater than six; at 0º, all will be transmitted because the data will add up to at least 3!

## The game

This game is collaborative between a large number of participants, although it is played individually in turns, and aims to demonstrate the random nature of quantum physics. The more participants who play, the better the statistics will be and the closer we get to the expected physical result. This can be achieved with several boards and by adding up the results at the end.
Each player is responsible for managing a certain number of photon pawns and run them on a lane of a certain colour (in principle one, but there may be variants of the game with each player playing on simultaneous lanes).
By filling in the following table, we can calculate the ratio between the photon pawns that have crossed the cascade of ‘polarisers’ and the total number of photons in play for each initial optical path.

| **Path** | Absorbed | Transmitted | Total | % Transmitted |
|---|---|---|---|---|
| Track P2 | | | | |
| Track P4 | | | | |
| Track P8 | | | | |

After the game, you can carry out the experiment in the elab remote-controlled laboratory with multiple polarisers using the QRcode below, verifying by experimentation the results obtained for two and four polarisers.

Remote experiment link

Experiment page link