**1: There is a whole scientific community interested in providing an indisputable proof that nature violates Bell's inequality. Explain why the Big Bell Test assures that they closed all the loopholes and what does it imply for our understanding of the universe.**

Quantum mechanics has brought a lot of uncertainty but, at the same time, new ideas to think about. New theories and scientific assumptions are emerging with the help of quantum mechanics. One of the most famous among those theories is what was once stated by Einstein regarding randomness. He defined the idea of hidden variables, which means that there is some unknown “force” that is driving randomness. That is, randomness is not actually truly random and that it could be predefined somehow. This was a mind-blowing statement that was shockingly disregarded by Bell, who introduced the well-known Bell’s inequality.

In order to check the validity of Bell’s inequality, the Big Bell Test Game was initiated. It was an idea to create a game for people who could, by playing it, generate a vast amount of data containing random choices of zeros and ones. Collected data was then used to do experiments that would prove that nature violates Bell’s inequality. Several problems and doubts were introduced that could arise during the experiments, which were called as loopholes. One example of such loophole is the freedom of choice loophole. What it suggests is that the random number generators that are usually used for experiments to create randomness could have some correlation and a predefined rule before the experiments were done. This will bring to some problems while trying to show the violation of Bell’s inequality. To address this issue, the Big Bell Test Game came along for help. The role of the random number generator in the game played the human who is perfect for creating truly randomness. Thus, the game tries to assure that all the data is collected in an actual random way. Another very interesting solution to the freedom of choice loophole was introduced by Zeilinger’s lab located in Vienna in their Cosmic Bell test paper. In their experiment, the role of their random number generator played the color of photon coming from two stars in different parts of the Vienna sky. Both lights were generated hundreds of years ago, making their chance of randomness very high.

The idea behind all the experiments done with the help of the Big Bell Test Game was to make sure that every loophole concerning the Bell’s inequality was closed. What I honestly think is that the factor that drives all the loopholes that were introduced during those experiments is the hope of people to find even a small “hole” in the Bell’s inequality and show that there is a chance to understand how randomness functions in nature. For now, violation of Bell’s inequality tells us that the universe is truly random and there is no way to predict it.

**2: Gamification is a powerful tool that can be used in several contexts, such as marketing and generation of products. Explain how The Big Bell Test experiment utilized gamification for generating random numbers and imagine and discuss other possible applications of gamification in quantum computing.**

Science develops with a huge amount of velocity and it is, actually, very crucial for our nowadays life. Today’s ambitions and challenges of life do not give to science to take a rest and often, a human being is not so free and full of strength to resist them and give counterattack in a form of solutions. So, computers come to the rescue and one of those rescue rings is gamification.

Now, about gamification via our example. So, Big Bell Test needs a huge number of data – human-generated random bits. Due to the game, a lot of people give to a scientist their needed data, without having any knowledge of quantum computing and without facing problems caused by difficulties of science. In fact, this is a great investment into the data for test and even more, this gives fun to so many people. Players- Bellsters, can share their results and rewards with the community – Twitter, Facebook, and leave feedback, this will attract more participants and will contribute to having good data. The game has actually all features, that the usual games have - levels, sound effects, animations, and power-ups, however, those are not so important in a field of gathering data. As usual games, The Big Bell Test also has challenges – to avoid being predicted by the Oracle (about this will talk later) and rewards after completing those challenges. For giving rewards and encouraging people to play and continue playing there are some levels:

1. Individual-level: Score for each level and cumulative score (for repeated play)
2. Community-level: Rankings, opportunity to create a group and to share their scores in social media
3. Scientific level: Game provides documentation about laboratories which used that data and the purpose of usage
4. Final reward: Short video captured from one of the laboratories, which explains to a user the purpose of the experiment. However, the final level is difficult even for experienced Bellsters,

This game looks like the famous game “rock-scissors-paper”. And the name of the “devil” of this game – Oracle, comes from the machine- learning algorithm used in this game. This algorithm predicts the Bellsters’ behavior due to past inputs. According to research, most of the time Bellsters spend playing the “speed game”. The requirement is to push 0s and 1s to run along the road, due to which player generates rapid bits, like – 000101001101, so on. After generating 20 bits, a player can see his/her “unpredictability”, which in the end makes an impact on the final score.

For not having extra difficult levels, they use beta testers, nevertheless, as I already mention, the final level is very difficult. So, this is a simple path, consisting of “players”, “Internet” and “Labs” but this helps a lot.

Now, about the usage of gamification in quantum computing. Last year, I write a Python code, which decodes and encodes any message. That was something similar to Caesar Cipher, the user writes a message, write the number, by which every letter will be shifted and get the encoded message, which can be decoded, only if another person will know the number by which the letters were shifted. So, as the future of our world and even more, of cybersecurity is on the quantum computing’s hands, I suggest making a game, playing which people will answer to different questions- giving “yes” or “no” responses and the continuation of events on a game will depend only on players response. The player will get history based on his imagination and scientist will get random keys- numbers, by which the message will be encoded, which can be unpredictable by hackers.

**3: Choose two of the thirteen nodes of the Big Bell Test experiment and compare their physical system, degree of freedom measured, rate of bits consumed and total number of bits, how where the bits used, how long the experiment took, and the distance between Alice and Bob.**

For this part of Task 3, we agreed to take those 2 nodes which have the almost same type of results. After some comparisons via Table 1, we choose these 2 experiments:

N 3: Bell tests with imperfectly random human input

N 6: Violation of Bell’s inequality with a single atom and single-photon entangled over 400 m

On Table 1, we can notice that only these 2 have results consisting of 2 numbers- SHRN and SQRN, where results of N 3 is SHRN = 2.639 ± 0.008, SQRN = 2.643 ± 0.006 and results of N 6 is SHRN = 2.427 ± 0.022, SQRN = 2.413 ± 0.0223. Now we will discuss each of them separately.

**N 3: Bell tests with imperfectly random human input:**

This experiment takes part in Shanghai during 30 Nov. and 1 Dec (2 days). The testing of this shows how well a measurement-dependent model will predict Bellsters’ behavior to produce the observed results and used entangled photon pairs. In this experiment, the distance from the source to Alice is 87 ± 2 m and the distance from the source to Bob is 88 ± 2 m, so the overall distance between Alice and Bob is 171 – 179 m. This much separation gives confidence that the detection stations of Alice and Bob will not have any effect on each other. During the experiment 1560nm seed laser is amplified and due to second- harmonic generation is amplified and upconverted to 780 nm. Cause of that laser, entangled pairs generated in Sagnac based setup then saved in single-mode fibers.

Via state tomography, they found out that the ideal state is approximately 97.5%. Using some calculations, they know that if input human randomness is more than 0.1495, MDL correlation cannot explain observed data.

Another state tomography showed that the ideal state is 98.7% (cos(69.1◦ )|HVi + sin(69.1◦ )|VHi).The locality and randomness loopholes were closed. All collected data were divided into 1 hour period for analysis.

Using human random numbers (a few thousand per second, used 80 Mb in 2 days), they obtain l0 = 0.10 ± 0.05 and to compare, they use quantum random numbers (100 kbps, used more than 500 Mb in 1.5 hours), they got a result- l0 = 0.106 ± 0.007. Those 2 are almost the same, but with different variations, and this is due to that quantum numbers are more in amount than human random numbers.

**N 6: Violation of Bell’s inequality with a single atom and single-photon entangled over 400 m**

This experiment takes place in Munich for 13 hours. The purpose of this was to show whether there is a difference between human-based measurement choice and machine-based measurement. With the comparison with N 3, this one used single-photon/atom entanglement.

During those 13 hours, 39614 events were saved, from which the choice of human random number was 19716, and the choice of QRNG was 19898. There we no so much difference in results, given that both sets had a strong violation of Bell’s inequality by more than 18 standard deviations.

The experiment had 3 different types of randomness – human-generated random number, quantum generated random number, and randomness in detecting a photon. The violation of Bell’s inequality was shown with a spin of a single 87Rb atom, which has a single-photon polarization state.

As it is mentioned in the title, the distance between laboratories was 400 m, and the photon, which already coupled in a single-mode fiber travels that distance.