A Conversation about Imagination, Love and Quantum Mechanics with Professor Edward Frenkel

Edward Frenkel is a Russian-American professor currently teaching at the University of California, Berkeley and has Mathematics running in his blood.

Frenkel grew up with a great passion for Quantum Mechanics, but later discovered the magic of Mathematics under the guidance of Evgeny Evgenievich Petrov, who taught him higher Mathematics and eventually "converted" him to the beauty of this subject. Because of the ethnic discrimination policies that were enforced in USSR's universities, he was not admitted to the University of Moscow. His only option was to enrol in the applied math program at Moscow's Gubkin University of Oil and Gas, widely knows by its nickname *Kerosinka,* which he describes in his *New York Times* bestselling book "Love and Math: The Heart of Hidden Reality" as "a kerosene-burning space heater, a low tech but effective response to adversity".

However, this did not stop him from following his dream of becoming a mathematician. During his study, he worked with notable scholars such as Boris Feigin, Dmitry Fuchs and Joseph Bernstein. Immediately after his graduation, he was invited to Harvard University as a Visiting Professor, where he was later accepted for his graduate studies and Phd. He then moved to UC Berkeley where he is currently teaching Mathematics.

Professor Frenkel exceeds any typical standard of what we imagine a professor looks like: he has that touch of madness and curiosity that made him more of an artist and polymath. He is a writer and filmmaker, you can see him on YouTube or talking at the well-known Colbert report show. Professor Frenkel tries to debunk the idea of Mathematics as an inaccessible and obscure subject. This is clear from the effort he puts in his book, in all his YouTube lectures and finally in his short movie – "Rite of Love and Death" (a.k.a. "Yukoku") – evaluated as "a stunning short film" by Le Monde.

As he will later explain: "Confining Mathematics in numbers and formulas is like following an art class that only teaches you how to paint walls, it leaves you with a bad taste in your mouth."

During our first Interdisciplinary Symposium, we, as students of the BA in Global Governance, had the honour of hosting Professor Frenkel as one of the speakers of the day. Useless to say how fascinating his speech on the word "imagination" was and its importance in an unlikely field such as Mathematics.

As we headed outside for lunch, we had the pleasure of interviewing our guest and learning a bit more about himself and his field of study. We have asked him some questions and the answers we received were incredibly interesting and absolutely worthy of a polymath.

"Generally speaking, how do you think infinity fits the concept of Mathematics and how can we interpret –or just merely envision, something that is perfect and has no end nor start? Infinity has been used as some sort of proof of God's existence by people like Descartes, but how can we, as finite beings, embrace the concept of something that has no end?"

First of all there are two types of infinity in mathematics: one is called potential infinity and the other one actual infinity. The first one refers to the concept that, for every number we can find another one that is equal to that first number plus one, leading to an endless list. That's easy to understand, but now try to imagine all these numbers at once, that is impossible.

In fact, there was a Zen master named D.T. Suzuki, who compared realization of the actual infinity with an "awakening" (which is called Satori in Zen). It cannot be described, but there are people who have experienced it and I believe every one of us can do the same. We often pretend that we are not capable of doing so, because we cage ourselves in a finite projection. Satori is, as Suzuki puts it, just like beholding the actual infinity.

Cantor was a German mathematician who theorized the first consistent theory on infinity at the end of the 19th century. He uses the notion of "set" (as a collection of things) and he described it as the whole collection of natural numbers which would then represent infinity. The problem is that this works well in Mathematics, but when logical thinking kicks in, we cannot behold all of these numbers at once. Yet it is possible sometimes that people experience such phenomena, some call it God, and I can see why they do so.

"It is quite a paradox, because Mathematics always needs proofs, but in the end we still make computations with infinity or with imaginary numbers, how do we resolve this contradiction?"

I have thought about this a lot and there is no real answer, but we can find indications, and they can only be found within ourselves. This process is not strictly mathematical, but lies in understanding what Mathematics is and where it comes from. The answer becomes paradoxical only if you assume that Math is a product of human activity: because as finite beings, we are not able to access infinity.

Mathematics is actually much more than computations and algorithms. For example: how come that Pythagoras' theorem has been simultaneously discovered in different parts of the world at different times and it remains always the same? If you compare it with literature you get a good grasp on the answer to this question: if Lev Tolstoj had not written "Anna Karenina", nobody else would have written it, while with Pythagoras' theorem this does not hold. It shows that Mathematics relies on some pre-existing and persistent truths which do not come from a single individual.

We can speculate that Mathematics lives in our collective consciousness, but it still remains a mystery. The latter resolves our paradox: because if Maths is beyond space and time and not born from specific individuals, then we infer that not even our collective consciousness is contained in space nor time. I think true reality is beyond any theory or idea we have of it, it is completely infinite, mysterious and magical.

"So, do you feel that this truth is internal or external of each single individual?"

Because we are all connected, I believe it is internal to all of us.

"In some sense it sounds a lot like Quantum Mechanics, holding up the idea of this great interconnection between all beings"

Yes. I believe it is possible to have connections that do not depend upon space nor time. We usually tend to dismiss them as "coincidences", but I think it is great that there are things we cannot completely grasp. Sometimes we just need to accept that there are mysteries. Some people have a more poetic way of saying it: they say we are all connected through our hearts, biologists have proven that we are interconnected in a continuous exchange of cells. The same applies if we say that, in principle, we all have access to Mathematics –even if some of us have a better one, it

explains the concept we mentioned before about Pythagoras' theorem and how it connects us with each other.

It is quite ironic: Mathematics is the most cerebral and rational subject, yet if we try to seek its origins we cannot truly give a rational and logical answer. Mathematics can give you a lot of information, but it is just not enough to understand the full complexity of the world.

Going back to your question on infinity: even the number of atoms that composes our universe is finite, it is a huge number, but it is finite. We do not normally experience infinity, yet mathematicians can talk about it. Cantor postulated that there are different sizes of infinity, proving in some sense that there are more real numbers than natural numbers, because you cannot establish a one-to-one correspondence between them, and to me the diagonalization method is one of the most beautiful mathematical theories.

The answer is that Mathematics itself comes from infinity; from that which is beyond any finite or confined space. But most importantly, we have to realize that what is beyond is not something foreign, something that descended from above, it is you, it is us. That's the key.

There is an ongoing subversion of science today. Scientists often make us believe that we know how everything works, but that's bullsh*t! We know that neurons compose the brain, but we have no clue how the brain works! Scientists have mapped the brain of a less than a millimeter-long worm called C. elegance and they have identified all of its 302 neurons and their respective connection, but have no idea about how that worm's nervous system works. Just imagine that the human brain has over 10 billion neurons.

If you start with the idea of being finite, you confine yourself in your body and your consciousness in your brain. This is why there is an immediate contradiction with the fact that we are actually able of perceiving infinity. This is why I believe we are infinite to begin with, but we are then forced to operate in a finite space.

"Would you be able to explain love with Quantum Mechanics?"

Not really, but Quantum Mechanics can show us that there is more to what we think we have fully understood of the world. 200 years ago Marquis P.S. de Laplace said in his theory: "give me the positions and velocities of all the particles in the universe, and I will predict the future". This would

lead to complete determinism. Luckily, 100 years later with the birth of Quantum Mechanics, and thanks to Heisenberg's uncertainty principle, we now know that it is not possible to know the exact position and velocity of a particle at the same time. That means that this whole premise (that you could know the position and the velocity of a particle at the the same time) can never be achieved. Of course, we can know them approximately, but the errors would then grow bigger and bigger after various computations, so the idea of determinism collapses. Quantum Mechanics saves us, because it shows that the mystery remains. In fact, every time Physics says: "we got it!" the truth just escapes. And I think we should take heart in that. It would be silly to say that Quantum Mechanics could explain love. On the contrary, it is love that is primary. I don't mean just romantic love, but love in a general sense; passion, we could say.

"Was this underlying sentiment that drove you to shoot your short film Rites of Love and Math?"

Yes, but I didn't understand it at the time. That's the beauty of art. I wanted to make a movie because I wanted to be famous overall… but in fact, now I see that in the movie I was expressing a desire to discover myself. We are often told by society that we need to achieve this or that when we are young, that we have to excel, but the only end that really matters is being able to do what makes you happy and what you truly love doing. The problem arises when you betray your love and passions for the sake of something that someone told you or because of the society you live in. The short movie came from my heart and it comes from my passion for truth.

"In the short you have included a very strong scene, that depicts the painful moment when you have to tattoo a formula on the stomach of your lover, why did you choose to include it and was the woman Mathematics herself?"

Yes, she was both Mathematics and Truth and the pain is the metaphor for "mental tortures" that Cardano talked about when he was led to introduce the "imaginary numbers". It symbolizes the struggle you have to confront yourself with in order to overcome difficulties and the efforts implied in doing so. But now, looking back, I have a different interpretation, which I did not understand at the time. I see now that she was both Mathematics and myself, my new self. The Mathematician in the movie was the old me that I wanted to kill –and he kills himself in the end, and she was what I wanted to be reborn as. The pain was also the process of death and rebirth, but I was not aware of it at the moment we shot the movie.

"You start off your book with a chapter on symmetries, where does that passion come from?"

Well, the reason why I started the book this way is because I think symmetry is a very good topic to show people who are not familiar with Mathematics what it is really about. Most people believe it is only about calculations and formulas, which is not the case. It is more like poetry, it is about ideas, it is very abstract and –just like for poetry, the form is very important. I think that it was a good way for me to break the ice.

Confining Mathematics in numbers and formulas is like following an art class that only teaches you how to paint walls, it leaves you with a bad taste in your mouth. Just like art is not merely painting a fence, symmetry is one of my best cards, it can be connected to both Mathematics and the real world, it does not include numbers and it is fundamental for Quantum Physics. Yes, there is more and you can understand it without any special preparation, because it is so elementary! Furthermore, symmetry touches us, it connects us to the beauty of form in our world by which we have always been captivated, merely because it is something that is imbedded in our reality. This is why I chose symmetries as an introduction to my readers, because if you think badly about Mathematics you most likely have never truly seen it.

Mathematics revolves simultaneously around perfection and mystery. While it may seem very far from a tangible subject, Math is everywhere; it surrounds us in all the aspects of our existence and it helps us embracing it in a more conscious way. The book "Love and Math: the Heart of Hidden Reality" enables the readers to have a new and refreshing perspective on this wonderful subject.

We could not thank Professor Frenkel enough for his precious insight and for the time he dedicated us. We will look at Mathematics in a different way from now on, we will try and question ourselves and our limits in order to get, even if just a little bit, closer to those mysteries that make our world a magical place.

With all our love and respect, hoping to meet each other again soon.

Delfina Belli and Riccardo Cavosi