QUANTUM AND HUMANITIES

The Wheels of Science

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“When our genes could not store all the information necessary for survival, we slowly invented brains. But then the time came, perhaps ten thousand years ago, when we needed to know more than could conveniently be contained in brains. So we learned to stockpile enormous quantities of information outside our bodies.

We are the only species on the planet, so far as we know, to have invented a communal memory stored neither in our genes nor in our brains. The warehouse of that memory is called the library.

A book is made from a tree. It is an assemblage of flat, flexible parts (still called “leaves”) imprinted with dark pigmented squiggles. One glance at it and you hear the voice of another person — perhaps someone dead for thousands of years. Across the millennia, the author is speaking, clearly and silently, inside your head, directly to you.

Writing is perhaps the greatest of human inventions, binding together people, citizens of distant epochs, who never knew one another. Books break the shackles of time, proof that humans are capable of magic.”

CARL SAGAN [1]

When I was asked to write about physics and literature, Carl Sagan’s words came to mind. I have not yet found a more fitting yet poetic description of what books have meant to our civilisation, probably because of the author’s emphasis on its potential for conveying

knowledge. In the field of modern knowledge, there is one area that arouses as much passion as fear: quantum theory. Fear, because it has been used as an amalgam and a colloquial expression to cover everything that sounds complicated. Passion, because its strangeness fascinates and entraps our imagination as if it were a black hole. So it is entirely understandable that this exciting area of modern research is the best candidate for literature to work its magic, and to use it as a lever for our imagination.

Does a lion know physics?

When I was starting my Physics degree, one morning I heard a brilliant comment from a professor about the difficulties we have in understanding quantum theory. We have all enjoyed fascinating documentaries on the animal world at one time or another. A common scene in these documentaries is that of a lion trying to hunt a fast-moving gazelle. With our hearts in our mouths, we watch as the gazelle begins to put distance between itself and its predator until, finally, the lion gives up and lets its prey escape. If we stop to think about this apparently simple situation, we will realise that while the lion is running, it performs some complicated calculations: it calculates its own speed and that of the gazelle, it computes the vector subtraction between the two, and when it realises that the modulus – or, in other words, the distance between the predator and its prey – is increasing, it gives up, and conserves its strength for another hunt.

However, any high school physics student would have difficulty putting these calculations on paper. And here the question arises: could lions be experts in physics? The answer is yes. Lions, like other animals – including humans – have evolved an intuitive way of using physics in their daily lives. Without physics, we would not survive in the asphalt jungle either. What we call *classical physics* grew out of our everyday observation of the world around us. We were able to predict lunar cycles by observing the sky, and define the trajectory of a parabolic shot by analysing what happened when stones and arrows were fired.

However, when we enter the world of modern physics, we go beyond the boundaries of ordinary human experience. It is obviously difficult to understand what happens when we move at speeds close to the speed of light, when the fastest speed that could be reached at the beginning of the twentieth century was about 100 kilometres per hour. How can we intuitively understand the uncertainty principle of an electron, if our eyes have not evolved to perceive this tiny particle?

> Atoms play by a very different set of rules from what we are used to seeing, and they do things that seem impossible to us

Quantum mechanics analyses phenomena that lie beyond the ordinary range of human experience, far removed from our intuitive view of reality. We have never needed it to survive. But that same limitation is fragmented by our ability to imagine the most unlikely

scenarios typical of the science fiction or fantasy genre. This is the area in which literature can help us – perhaps not to convey quantum vicissitudes accurately, but to ignite the flame of curiosity that drives us to continue learning.

What is quantum physics?

Human beings have felt the need to understand the universe since the dawn of time. The pinnacle of this research in the field of contemporary physics, is organised around two major theories: quantum theory and relativity. While relativity describes the macroscopic world and the motions of galaxies, quantum theory reveals the enigmatic behaviour of atoms and their tiny constituents, the building blocks of everything around us – and even ourselves. These tiny particles play by a very different set of rules from what we are used to seeing in our everyday lives. They do things that seem impossible to us: they can appear out of nowhere, be in two places at once, behave like a wave or a corpuscle depending on how you look at them, pass through walls, share *spooky action at a distance* (as Einstein himself put it) and many other apparent extravagances.

The new physics invites us to challenge our beliefs and consider questions of great intellectual beauty: is there a single, objective reality? Does the Moon exist in the sky when we are not looking at it? Do we follow a predefined script in our existence, or do we write it as we go through life? Although quantum physics continues to disturb anyone who tries to understand it rationally, its scope of action goes beyond the abstract and distant realm of ideas. We could succumb to the error of thinking that the credibility of this science is open to question and based on speculation. But the truth is that it is the most accurate theory science has ever formulated. There is as yet no known experiment that can disprove it, or any failed prediction. Faced with quantum theory, we have two options: “shut up and calculate” in order to obtain all kinds of technological breakthroughs. Or else, the second one, dare to interpret what the universe is trying to tell us.

If we opt for the first approach, we will not experience the disturbing confusion that quantum physics and its paradoxes lead to. But if we want to go beyond equations into the provocative mysteries of the quantum world, we must cross the boundaries of physics into the realm of philosophy, including metaphysics – in etymological terms, beyond physics. There is a story about a student who asked the Nobel laureate Richard Feynman, “What really is the quantum wave function?” The professor simply replied, “Close the door first.”

Little big questions

In my introductory lectures on physics, I like to start by asking questions: what does science mean to you? I often see grimaces of tension on the faces of my audience. They are undoubtedly casting their minds back to their student days, when they were confronted with those diabolical mathematical equations, full of numbers and strange symbols that conveyed little – or nothing – to them. As a result of these experiences, the vast majority of people associate science with something that is complicated, boring, and far removed from their daily lives and concerns. However, science can bring much more to our lives than

these cryptic formulas that only a few people can understand. It opens the door to a fantastic world in which imagination and dreams cross the frontiers of the impossible and surprise us by becoming reality. Will we ever manage to teleport? Will we have a DeLorean – the car from *Back to the Future* – parked in the garage for time travel? Will we be able to explore distant galaxies by defying the speed of light? Will we ever enjoy invisibility cloaks like Harry Potter's?

These are questions we ask ourselves as children, but as we get older, we become convinced that fantasy should remain in the world of dreams and not in the world of practical everyday life. I recently read that a 4-year-old child asks an average of 473 questions a day. We start our lives as little explorers and uninhibited researchers, unafraid of failure. A good example of this is a story by a colleague, who told his young daughter about the theory of relativity: "Last night I told her that the speed of light is the speed limit of the universe. I was speechless when she asked me: so dad… what's the speed of darkness?" The questions asked by the youngest children may seem deceptively simple, but they are often those that have transformed our view of the cosmos. Why do we stop asking them as we grow older?

Perhaps because we are busy with our daily chores, or perhaps because we drag our own fears of failure around with us, we adults do not know how to deal with questions such as the following: "If the moon revolves around the Earth, and the Earth revolves around the Sun… what does the Sun revolve around?" We often freeze up and respond with something along the lines of: "Don't you want to go out and play for a while? That way you won't bother the grown-ups." There is no more effective way to clip the wings that allow our little explorers to fly. However, if we accept a child's invitation to ask ourselves this question, we may discover something amazing.

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If we travel 26,000 light years from our planet, we will find the centre of the Milky Way. Something very powerful must be at work for all the stars, including our Sun, to revolve around it. This is indeed the case: there is a supermassive black hole, which weighs millions of times more than our Sun. And this is not only true of our galaxy, but for most of the galaxies observed by astrophysicists. These monster holes have turned out to be not just cosmic destroyers, but also play a fundamental role in the creation of galaxies and thus in our own existence. They were responsible for gathering interstellar dust, creating stars and solar systems. They are a decisive element in creating everything that illuminates the firmament. They lead the dances of the galaxies!

We are stardust

There is an immense potential in science that is often untapped: that of offering us context and meaning in life. When we teach science to children, we quickly focus only on the details. On solving an equation or in the components of this cell, or that one. If we don't take children to the stars and beyond, science becomes inert. But if we communicate it by showing them the great ideas that emerge from it – how it allows us to travel to new worlds, explains why the Sun heats us, or how the iron in our blood, the calcium in our bones and the oxygen in our lungs are forged in the explosions of the stars – then science comes alive. Then we become aware that we are heirs to the 14-billion-year legacy of the universe. They say that astronomy is character-building. Understanding our small place in that ephemeral instant of the cosmos is a journey of humility. Children are the key to our future, so it is important that they start exploring the big things from a young age. This makes it imperative to focus our efforts on those who have science at their fingertips, and there is no better vehicle for this than literature.

Warning signs

Of course, our children are not the only ones we should focus our attention on. As a good friend says: stories are used to put children to sleep and wake up adults. And the times we are living through are quite tortuous. These are not easy times in the economic sphere; the newspapers and television news programmes are full of reports about the brain drain. Our young people, the future assets of our society, are leaving us. In science, the shortfall in research budgets is alarming. While the European average stands at 2.32% of GDP, in Spain we are far behind, with a budget of 1.41% in 2020 (although the effect of the decline in GDP due to the pandemic helped to increase the figure) [2].

However, it is true that in times of hardship and cutbacks, living as we do in a democracy, it is right that it is society, which is all of us, that decides where to invest our money and what our main needs are. This is precisely why it is important that we have the necessary information and knowledge to be able to make these decisions. That we are aware of the advantages of investing in talent, knowledge and research. According to the Bloomberg Innovation Index, the ten countries in the world with the highest levels of well-being are also the most innovative. What they have in common is that they invest between 2% and 3% of their GDP in research, development and innovation (RDI).

Inspiration pays for itself

This image, known as "Earthrise", was the result of a major research undertaking: *Apollo 8* orbited around the Moon. It was taken more than 50 years ago, on Christmas Eve 1968.

The Earth seen from beyond the lunar surface Source: NASA

Discussing the image, NASA's Bill Anders said: "After all the training and studying we'd done as pilots and engineers to get to the moon safely and get back, and as human beings to explore moon orbit, what we really discovered was the planet Earth." However, something that is not taken into account as often as the Apollo programme's exploration of space is its cost. In other words, although we can argue how wonderful this great achievement was that gave us photographs like this, we can ask ourselves…. It cost a packet, didn't it? Many studies have been conducted on the efficiency of Apollo's economic impact. The most important was the Chase Econometrics study in 1975. The study showed that for every dollar spent on the Apollo project, the United States economy earned 14 dollars. The Apollo project paid for itself in terms of providing motivation to progress, in engineering, in discoveries. The inspiration paid for itself.

It is not that richer countries invest in science; countries are richer because they invest in science. According to the 2012 report by the Círculo Cívico de Opinión, if Spain had invested the same percentage in R&D as the rest of the OECD countries since 1970, we would be 20% richer per capita. The lack of knowledge of breakthroughs and what they mean if we are to continue to evolve as human beings can "cost us dearly". As Carl Sagan said in *Cosmos* (1980): "I believe our future depends powerfully on how well we understand this Cosmos in which we float like a mote of dust in the morning sky."

Mental diet

The major question for consideration at the moment is the following: what is in our interest as a society? All too often this is what the media and the various brands are promoting. Most of us will immediately recognise people like Cristiano Ronaldo, Silvio Berlusconi, Jstin Bieber, Karmele Marchante, Victoria Beckham, David Beckham, Jorge Javier Vázquez, Carmen Alcayde, Maradona, Kobe Bryant or Arnold Schwarzenegger, as they are celebrities

and millionaires. We are interested in what they wear, what cars they drive, and where they have gone on holiday.

But there are others who will leave a much more lasting imprint. But how many of us recognise Alexander Fleming, Manuel Elkin Patarroyo, Marie Curie, Richard Feynman, Sir Tim Berners-Lee, Wilhem Conrad Röntgen, Elizabeth Blackburn, Carl Sagan, Wojciech Hubert Zurek, Anton Zeilinger or Juan Ignacio Cirac?

This group may not be rich or famous, but they are the people who have made us evolve the most. They have given us penicillin, vaccinated us against malaria, fought against cancer, enabled us to connect to the Internet, have X-ray or MRI machines, and given humanity countless other gifts. We must review the value and belief system that establishes who our heroes and role models are.

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In the same way as we take care of the food we eat every day, it is essential that we take care of our mental diet and be aware of the contents we eat. Perhaps Jean de la Fontaine was right when he said that “All the brains in the world are powerless against the sort of stupidity that is in fashion.” At first I disagreed with this statement. I was reluctant to acknowledge how correct it is. Then I resigned myself to accepting the truth of his words. But my resignation evolved, and I said to myself: why not turn it around? If that is the way things are, we must turn it to our advantage. We can make science interesting, we can make it fun; let’s enhance knowledge. Let’s make science fashionable!

The Earth Library

We can evolve as a civilisation, or we can self-destruct. Avoiding the latter involves making knowledge available to every human being on the planet. It is our responsibility as scientists to make science understandable, and it is the responsibility of those responsible for education to convey it passionately in the classroom. In turn, the media have a responsibility to choose their programming responsibly, and politicians must allocate decent budgets to research and to the brilliant brains we have in our country who have no choice but to go abroad. But most importantly, it is our right, the right of all of us, to enjoy knowledge, for it is knowledge that will lead us as a civilisation to achieve all our dreams.

REFERENCES AND FOOTNOTES

1 — Sagan, Carl (1980). *Cosmos*. Random House
2 — Data taken from Bancomundial.org

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