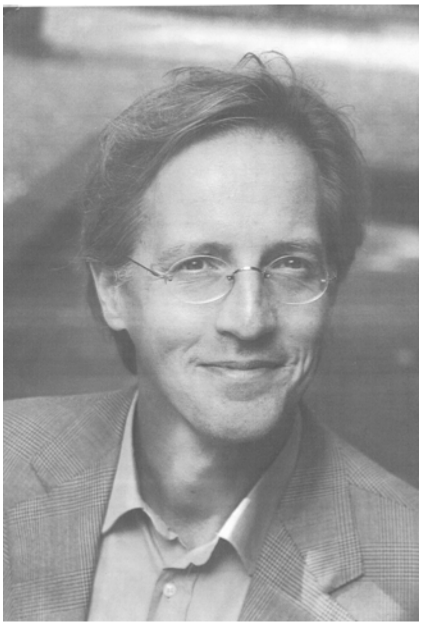
Robbert Dijkgraaf



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On 1 July of this year, Dutch theoretical physicist and mathematician Robbert Dijkgraaf, well known for his research into string theory and interfacing mathematics and physics, will become head of the Institute for Advanced Study in Princeton, USA. I spoke to him about current developments in his fields, the need for interdisciplinary cooperation and embracing complexity.

Where will the emphasis of your long-term research programme at Princeton lie?

The focus of my long-term research will be on developing the classical approach to science further, based on new discoveries about nature. In recent years, Princeton has been an ongoing success story, but the work is far from complete. Wherever I go – and that includes Princeton – I always work from the idea that physics and mathematics can enhance one another in many ways, and that there is plenty of scope for cross-pollination between other disciplines.

I find it inspiring to see a formula reappear in different places, acting as a kind of Rosetta stone, bringing different interpretations together and clarifying them. Over the centuries, physics has provided a context within which problems can be pondered with mathematics. As far as the interaction between mathematics and physics is concerned, we experienced a kind of 'golden age' from the late sixties to the early seventies. Mathematics as we know it is still largely based on our everyday intuition, and familiar things such as counting and geometry. A great deal of geometry was developed from the context of the night sky. But what would happen if we rebuilt it on the principles of quantum theory, for example? Or if we introduced more dimensions into geometry than the three we perceive directly? If you look at numbers in a new way, you can perform a whole new set of calculations. Fermat's theorem, for example, was proven with the help of geometry, after centuries of attempts.

Crossing interdisciplinary boundaries seems important to your work...

At times, the entire physics community appeared to be working on one single topic, such as holography or string theory. However, today's young researchers combine subjects from very different areas, moving through different fields of study. Someone might be studying black holes and string theory, and then applying their findings to condensed matter. We're bringing different worlds closer together and, from there, developing ideas about new, exotic forms of matter, black holes, elementary particles and cosmology, which all come together in a single model. Certain theories or parts of theories can be re-used in different ways. To me, there's something quite artificial about segmentation between different disciplines. I like the fact that people can now more easily cross interdisciplinary boundaries.

Where do you see major developments in physics taking place?

We seem to be in an era of searching. Similar periods in the past have often turned out to be fruitful. Fantastic discoveries were made, even though they often took a while to mature. Several large projects are currently receiving a great deal of attention – the Large Hadron Collider and Planck telescope, for example – but there is also a lot of really interesting stuff taking place in the field of theoretical physics. If anybody were to ask me where the next big thing might come from, I'd advise them to spread their bets!

String theory has already provided compelling evidence for the fact that space and possibly time are not the foundation of all nature. The validity of this idea has been conclusively demonstrated by research into black holes, holography and the work of Juan Maldacena on equivalence in systems with and without gravitation. If we take Einstein seriously, we know that space and time are two sides of the same coin. As we study processes which take place close to the big bang, a different description of time becomes relevant. Just as space disappears as we approach a black hole, time should disappear as we approach the beginning of our universe.

Do you find theories of the non-existence of the big bang plausible?

I find the ideas of theoretical physicist Erik Verlinde regarding the possible non-occurrence of the big bang very exciting. His thinking fits in with developments which have been going on for some time now. A huge explosion at $t = 0$ appears odd when we consider the fact that the concept 'time' becomes irrelevant close to the beginning of our universe. We may have to abandon the idea of the universe 'coming into existence' and developing in time. That's pretty exciting.

A comparison: if we trace the source of a river, the stream becomes narrower as we climb the mountains and then we'll come to a point where there's just some condensation or a few droplets on a rock. This might be the beginning of what will eventually become a great river, but it originates from a completely different system. Similarly, one might picture our universe as something that springs forth from quantum mechanical systems and conditions that we can't observe directly. So we may need to abandon our familiar Newtonian ways of thinking about physics, and adopt a radically different approach. I agree with Verlinde's intuition, but we need a concrete model which we can subject to further examination. There's no extensively tested mathematical model yet which would allow us to simulate processes in detail.

This burden of proof is immensely important. Why has cosmology made such huge qualitative advances? Not just because we have a greater understanding, but also because we have far more detailed, extremely precise measurements. At the end of this year, we'll be seeing some interesting new data arrive, measurements of gravitational radiation made by the Planck satellite. That should tell us something about the way in which gravity has behaved under extreme conditions. On the basis of these new findings, several cosmological theories will end up in the rubbish bin, but that's just part of the game. Of course, it is very exciting to live at a time in which these kinds of measurements are taking place.

How has science advanced since Einstein's time at the Institute for Advanced Study?

Einstein could come up with the notion that time depended on gravity, but he had no way of measuring this. His ideas weren't corroborated until the eighties, with the help of atomic clocks and jet aircraft. He really was fifty years ahead of his time. Using thought experiments, Einstein was able to test the consistency of his ideas. That's how he came up with the special theory of relativity. Einstein had ascertained that an observer might make some very strange observations from his frame of reference, and then drew the most logical conclusions regarding the acceleration of that observer.

In the twenties, a vast quantity of astrophysical and cosmological readings became available, which stimulated the demand for a broad, universal theory of gravitation. Today, we're in a similar situation. We're observing some strange things, such as dark energy and matter, an odd acceleration of the universe and the way gravitation behaves on a galactic scale. We see the ragged edges of Einstein's theories appearing.

Do we need to visualize the processes that created our universe in order to understand them?

Einstein attempted to visualize the quantum world, and perhaps that's not such a good idea. We're just not equipped to imagine certain things. When I try to envisage the position and velocity of particles from the perspective of classical mechanics, I picture small marbles which occupy a clearly defined spot and move at a certain rate. In quantum mechanics, you can't determine the position and velocity of a particle at any given moment, and in terms of traditional physics, that is hard to imagine. Today, our attitude is more along the lines of 'so be it', or 'just shut up and calculate'! That doesn't mean we should stop thinking, though. We need to consider new interpretations, not so we can neatly fit everything into the existing perceived order of things, but to take a step ahead.

Is there still room for intuition and coincidence?

If we determine that nature works in a certain way, then theoreticists will immediately wonder 'why?'. What reason might nature have for a certain property or inclination? Fortunately, the universe offers us hints, albeit very few. These clues show us that there is still a new story to be told about the universe and matter. Unfortunately, it can take a huge amount of work, spanning decades and costing billions, to unravel one such hint. Yet sometimes nature will just drop something in our laps. Like when the muon was discovered, the leading Nobel Prize winner, Isaac Rabui came up with his famous remark: 'Who ordered that?'.

We are currently looking for the Higgs boson, but we may well measure something just as important in its direct vicinity. Also, we shouldn't forget that huge steps can be taken purely by thinking. We need to keep reflecting on the few building blocks that we have at our disposal. If you want to trace back the entire path of nature by means of measurements, that would be extremely time-consuming, but if you already have an idea of where to look, you can plot out a clear line to follow.

So physics can offer elegant, simple solutions, but sometimes we just have to accept complexity...

In physics, people spent years looking for a 'holy grail', a neat theory that would explain and predict everything. Nowadays, we accept the complexity and apparent contradictions which exist within the universe. We can have several theories at once that don't overlap, but which are all correct in their own right. They can coexist, even if they contradict each other. There's no reason to assume that reductionism, breaking things down into simplified processes, should always work. The foundations of our reality are largely mathematical, but there are also scientific domains in which complexity just seems to keep increasing.

As a theoretical physicist and particle physicist, I belong to a privileged group. The world we deal with can largely be described in elegant formulas. Maybe, for that reason, we think about complexity a little too easily. Scientists studying climate models, for example, probably don't expect to come up with single-line formula that will accurately predict the weather over the next few years and I imagine biologists might consider the search for simplified laws as an occupational hazard of physicists. The fact that we speak of the 'laws' of nature is telling in itself. But those 'laws' only apply to that which we can observe and measure directly, and their longevity can turn out to be limited. Sometimes, we need to embrace complexity and take it seriously in order to arrive at new insights. Where there's no shortcut, we'll just have to take the long route.

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