////Title: Causality: A Fundamental Necessity or Part of the Problem?

////Standfirst:

For thousands of years, the notion of a one-way flow of cause-and-effect has underpinned virtually every scientific theory. Yet Dr Martin Tamm at the University of Stockholm argues that this notion of 'causality' may be holding back our understanding of how the Universe really works. Through his research, he suggests an alternative approach, based around a mathematical construct named 'probability space'. His ideas could ultimately lead to new solutions to problems that physicists have struggled with for decades.

////Main text:

The concept of cause-and-effect is deeply engrained within the ways in which we view the world. When we think of any event – whether it is a leaf dropping from a tree, or the dramatic collapse of a dying star – it seems obvious to us that it must have been triggered by a sequence of other events, which occurred in its past. Because of this, many of researchers believe that cause-and-effect, otherwise known as 'causality', is a fundamental property of the Universe. But is this really the case?

Causality has now been extensively discussed by philosophers and scientists alike since the time of Aristotle, some 2,500 years ago. All the same, we still don't have a clear idea of how it should be described. Because of this uncertainty, some researchers now argue that causality may not be fundamental after all. Although it works very well for most purposes, in fundamental physics it may be an illusion. As we evolved, these researchers suggest that we naturally came to view every event through the lens of cause-and-effect, making it incredibly hard for us to see the world in any other way.

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In his most recent study, Dr Martin Tamm of the University of Stockholm argues that an unquestioned assumption of causality may be preventing us from gaining clear answers about the nature of the Universe. As an alternative, he suggests that we should instead conceive the world as a 'probability space'. This space is a mathematical construct, containing a set of all possible occurrences; a set of all sequences of events that could lead to them; and a description of the probability that each occurrence will actually occur.

Within this description, a physical system can develop into several different states at any given time, without causality playing any fundamental role. The idea contrasts completely with those that have dominated every aspect of scientific theories so far. Crucially, however, it is compatible with existing ideas, in the landscapes of both quantum and classical physics. To explore the implications of viewing the world as a probability space, this study takes a fresh look at three well-known problems in physics – which so far, have only been investigated through the lens of causality.

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In the 1930s, the field of quantum mechanics was in its infancy, and many new ideas were emerging that appeared to turn our understanding of physics on its head. Among these was the concept of 'entanglement', which suggests that the fates of two particles could become intrinsically linked. Through this effect, any action taken on one particle could immediately affect the state of the other, no matter how far apart in space they are separated.

Inevitably, the idea didn't come without controversy. In a famous thought experiment published in 1935, Albert Einstein, together with physicists Boris Podolsky and Nathan Rosen, argued that entanglement must be impossible, as it would allow information to be transmitted between two entangled particles at faster than the speed of light. In contrast, Einstein had showed in his earlier theories of relativity that this is strictly forbidden by fundamental physical laws.

If we look at the problem from a different angle, the problems presented by the trio, now named the 'EPR Paradox', may not actually stem from quantum mechanics, but from the concept of causality itself. if we instead think of the possible states of two entangled particles as existing in a probability space, the time taken for information to travel between them essentially becomes irrelevant. As a result, the predictions of both relativity and quantum mechanics can be upheld.

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The next problem explored in the study relates to the accelerating expansion of the Universe. When astronomers turn their telescopes to distant galaxies, they notice a clear relationship between their distance, and the speeds at which they are moving away from us, which seems to demand the presence of a vast yet unseen source of energy that drives galaxies apart at an ever-increasing rate. Named 'dark energy' by cosmologists, this phenomenon has remained one of the greatest mysteries in physics for the last few decades.

Yet this phenomenon could have a far simpler solution. If we insist that the future should be considered exclusively as a consequence of the past, our theories may be missing some fundamentally important components. Instead, this study suggests that cosmologists should consider the probability space containing all possible universes. In turn, the accelerating expansion may emerge as a natural consequence of simpler physics, without the need to introduce such a baffling, causality-dependent concept as dark energy.

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Finally, the study considers the direction in which time itself flows. In our conventional understanding of cause-and-effect, this flow must be completely asymmetrical. Otherwise, events would be just as likely to trigger outcomes in their past than in their future. In the face of this universally-accepted idea, this study asks: could causality be preventing us from viewing the actual flow of time as a symmetric process? If this is the case, causality may not be fundamental after all. This idea could have profound effects on virtually every aspect of how we view the world.

While causality will always be essential to our understanding, Dr Tamm suggests that if we are to truly comprehend how the Universe works, we should remain open to the idea that it may not be a fundamental necessity. Altogether, he hopes that through a more widespread consideration of the roles played by probability space, new breakthroughs could emerge in areas that have continued to stump physicists and philosophers for thousands of years.

This SciPod is a summary of the paper 'Is Causality a Necessary Tool for Understanding Our Universe, or Is It a Part of the Problem?', from *Entropy*. doi:10.3390/e23070886

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