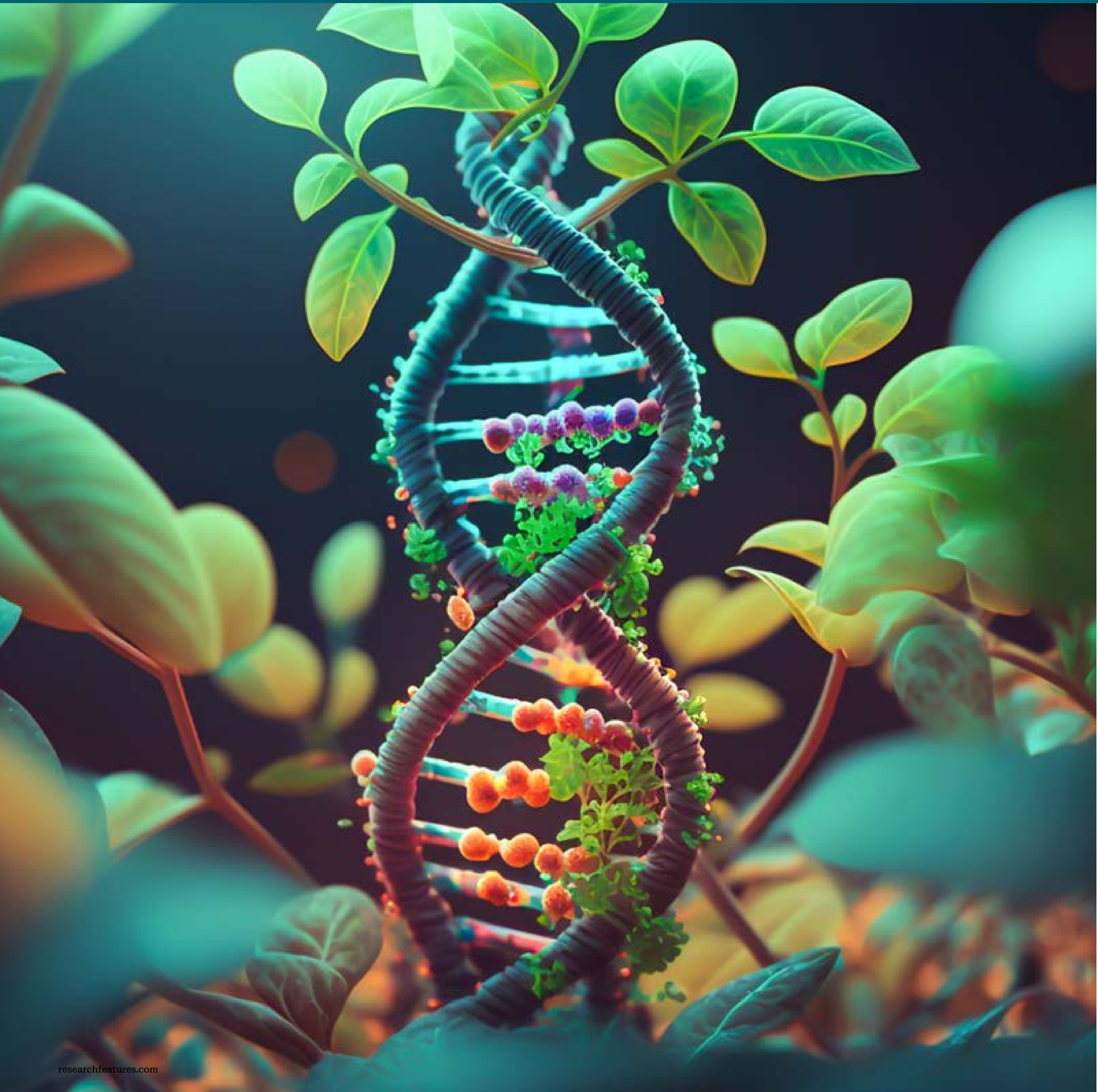

Theoretical biology

Describing life with mathematics

- Researchers have long sought to explain biology in terms of the unbreakable laws of thermodynamics.
- Through his research, Dr Richard L. Summers at the University of Mississippi, USA, outlines the mathematical foundations of a 'theoretical biology'.
- His theory aims to express living organisms in terms of the information flowing through them as they interact with their environments.
- This could ultimately lead to new insights into the nature of life itself.

The question of what life actually is has captivated the minds of scientists and philosophers for thousands of years. Given the unimaginable complexity of living systems – including ourselves, many have found it impossible to accept that life could be governed by the same physical laws that dictate the bonding of atoms and swirling of galaxies. Yet for many scientists, proving these connections is a key challenge.

Researchers often draw their ideas from mathematical formulations of complexity. Here, intricate dynamics can emerge from the interaction of many simpler elements: from global economies fuelled by individual financial transactions to swarms of birds, fish, and insects which manoeuvre themselves in shapes and trajectories far more complex than any individual could conceive.

Altogether, these systems abide by the same famous rule: 'the whole is more than the sum of its parts'. For Richard L. Summers at the University of Mississippi, USA, simply recognising the emergence of complexity isn't enough, however. Through his research, Summers aims to prove how the complexity of living systems is ultimately expressed in the same mathematical principles as other physical systems.

Definitions in entropy

In 1943, Erwin Schrödinger presented a lecture which laid the groundwork for these ideas. Named *What is Life?*, his landmark presentation and resulting book made a connection between living systems and the flow of entropy, a term which quantifies the randomness and uncertainty of all physical systems. As Summers describes, 'Schrödinger proposed that an understanding of the true nature of living systems first requires an apprehension of their ability to control entropy dynamics in their environment.'

These interactions are governed by the second law of thermodynamics, which states that the entropy of any closed system must always increase over time. Entropy can be defined mathematically in many ways – but in this context, it is best described in terms of 'information theory'. This branch of mathematics aims to understand the world in terms of the transfer and storage

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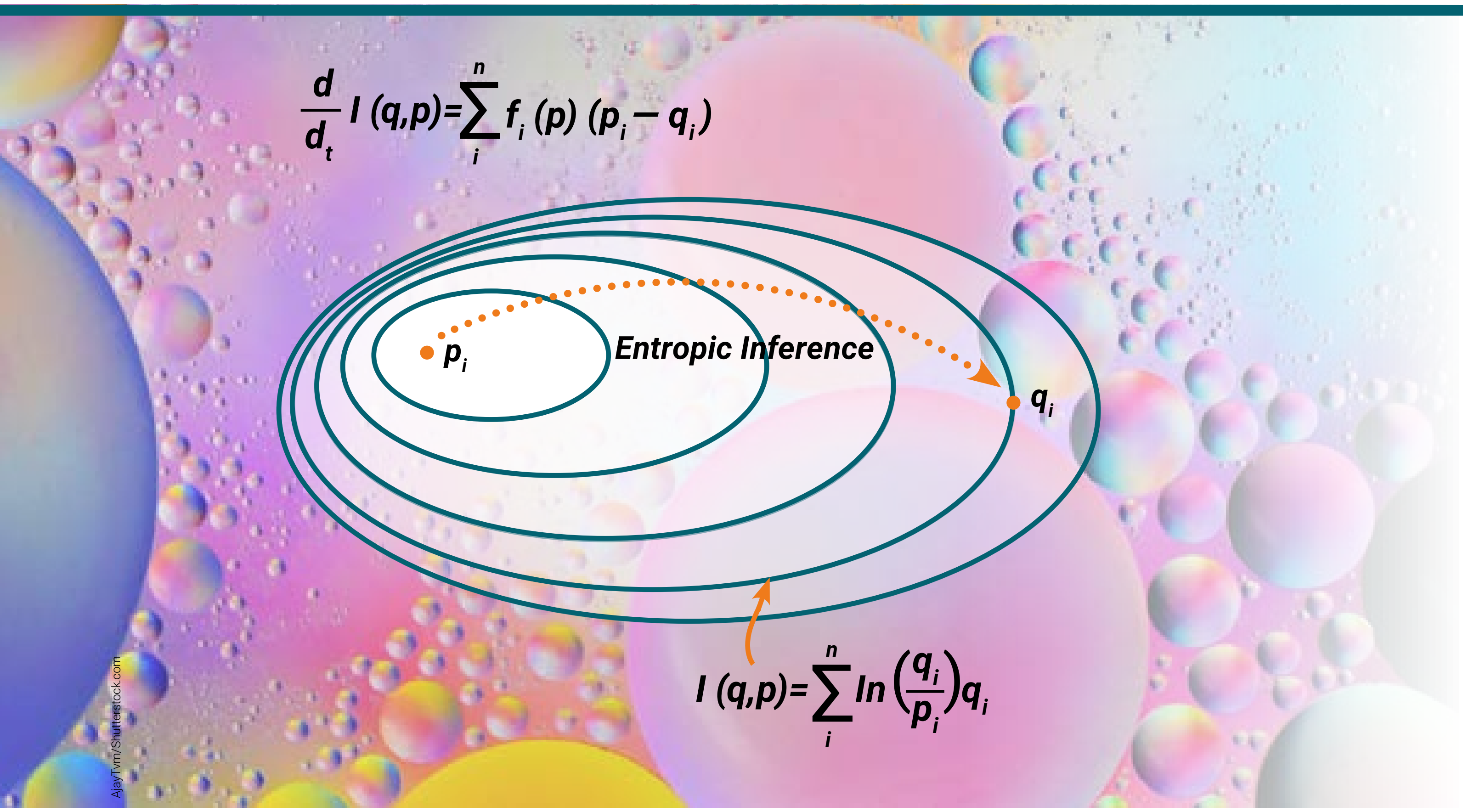

of information, broadly defined as the resolution of uncertainty surrounding the possible outcomes of an event. In this case, entropy can be defined as the average uncertainty associated with an event's possible outcomes.

Biological currency

Taking this idea further in a 1957 study, distinguished physicist E. T. Jaynes showcased a new proof of the second law of thermodynamics. It involved a macro-scale of the Boltzmann formula, which elegantly equates entropy with the number of possible arrangements of particles in a system. For the first time, this idea provided a clear link between information theory and thermodynamics.

Although Schrödinger didn't have the mathematical tools to adequately describe his ideas in 1948, each of these principles have since been pieced together to show that living organisms are thermodynamic systems – which, despite their immense complexity, can be described using the same principles as any other physical system.

Summers takes this concept even further, suggesting that as interacting thermodynamic systems, organisms exchange information as a 'biological currency' as they influence and are influenced by movements of mass and energy in their surrounding environments. 'The algorithmic processing of information is posited to be the most essential function of living systems', he explains. 'In fact, it is the ability of these biosystems to acquire information signals and translate that information into a meaning for adaptive actions that is critical to their stability and survival.'

From information to meaning

Just as physicists use mathematical theories to explain and predict experimental results, Summers believes his ideas pave the way for a new field of 'theoretical biology' where organisms are studied under the same principles as any other system in nature. In this context, living systems are defined by their capacity to acquire information and convert it into forms more relevant for their survival – whether that may be converting the chemical energy in their food into warmth or harnessing currents to gain speed and altitude.

To achieve a robust foundation for theoretical biology, Summers would first need to express these mechanics in terms of a new computational methodology – which expresses the creation of information as organisms perceive and experience their environments. 'The process of translating the information to meaning requires the living system to bridge the gap between the physical constitution of its environment and functional aspects of its system dynamics', he illustrates. In other words, an organism must be viewed simultaneously as part of its own environment and also as a thermodynamic system in itself which stores, processes, and transfers information.

An equation for action

To build his methodology, Summers drew from two key equations: the first of which quantifies the difference between the information carried by two systems, while the second is a mathematical expression of Darwin's theory of natural selection – describing how traits which help organisms to survive and reproduce more easily are more likely to be passed on to future generations. By combining these equations, Summers could finally develop an 'action measure' to express the flow of information through living systems in a single, elegant equation.

Summers ultimately hopes his ideas could have far-reaching implications for our understanding of the fundamental nature of life, and its connection with the unbreakable laws of thermodynamics. 'This formulation of the actionable knowledge acquisition and translation procedure serves to describe the general dynamics and the generation of meaning in living systems', he summarises. Simply put, theoretical biology could soon bring researchers a step closer to answering key questions about the fundamental nature of life itself.

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Personal response

How did you first become interested in describing living systems in terms of thermodynamics?

In my undergraduate training in chemistry I was first introduced to the Second Law of Thermodynamics and was instantly intrigued by the mysterious nature of entropy dynamics. At that time, I intuitively felt that this strange property of energy and matter would be a major key to understanding the organisational structure and processes of living systems.

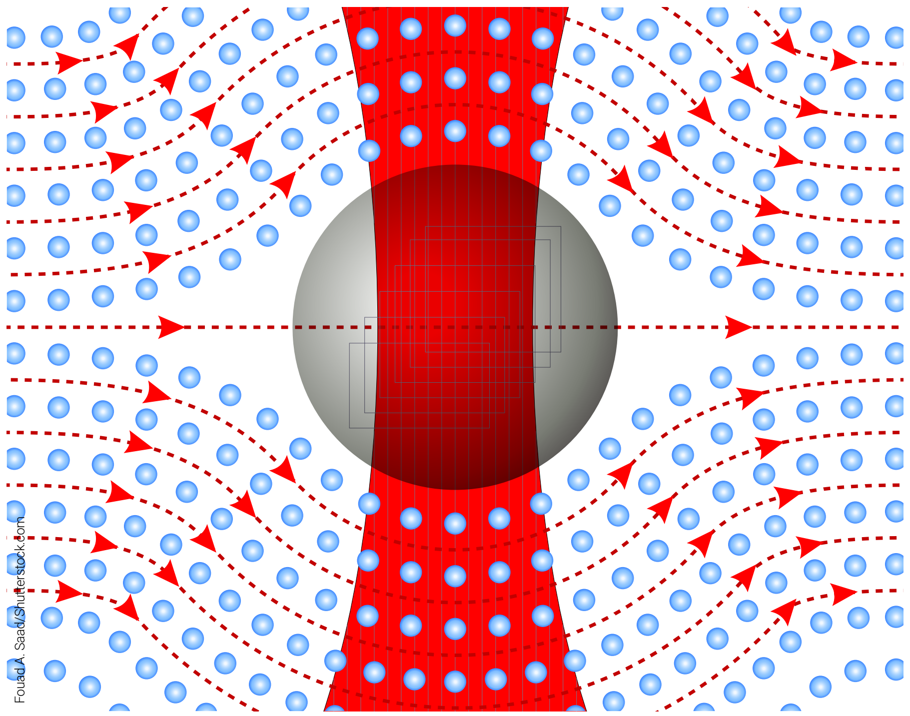
Can theoretical biology be applied to studying specific species of organism?

Yes, in fact, a robust theoretical biology should be applicable across all forms of living systems.

One of the ideas that I have explored is the demarcation between sentient organisms and more primitive living systems. The experiential process as described by my proposed information-theoretic framework allows for a layering of the procedures in a way that there is a global experience of the sum of all other discrete experiences of the organism. In this way, I think conscious experience can be thought of as the overarching experience of the amalgamated whole of information-sensory inputs. An information-based theoretical biology might even allow for us to more readily identify noncarbon based life forms if they fit into this foundational framework as meeting the criteria as 'living'.

Could theoretical biology inspire more collaboration between biologists and physicists?

Certainly! The problem that has prevented much collaboration in the past is that the two disciplines speak very different languages and have diametrically inverse perspectives. This experiential-based analytic approach to a theoretical biology provides for a common mathematical and algorithmic framework that flips the perspective from the canonical microscopic causal impetus (the reductionist view) to a primary perspective where the whole of the living system embedded in the environment of its biological continuum is the causal origin of the known state of its physical reality. So rather than a reduction to physics, there is a reduction to the fundamentals of experience as the process-relational causal framework. This shift in perspective allows for a restriction in the degrees of freedom in living systems to overcome the forces of entropy. Experience mediated cohesion and coherence creates the constraints for this singular degree of freedom for the living system as the totality of details of the organisational state is always known to the organism. By intrinsically knowing these states through experiential self-reference, the living system has the unique ability to transform the overall qualification of energy into work. The experiential process also allows living system to continuously recreate the dimensionality, substance, and properties of their knowable physical reality.



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Bio

Dr Richard L. Summers has been a Distinguished Guyton Professor at the University of Mississippi and was the lead scientist for the NASA Digital Astronaut Project. He is the recipient of the prestigious Sebetia Ter International Award for Biomedical Research and author of the book *'Experiences in the Biocontinuum'*.

Further reading

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