The properties of a piece of matter are defined not by the basic building blocks themselves but by the way they are organised into hierarchies. This paradigm — where structure defines function — is one of the overarching principles of biological systems, and the key to their innate ability to grow, self-repair, and morph into new functions. Spider silk is one of the most remarkable examples of nature’s materials, created from a simple protein spun into fibres stronger than steel.

As we begin to appreciate the universal importance of hierarchies, engineers are applying this understanding to the design of synthetic materials and devices. They can gain inspiration from a surprising source: music.

In the world of music, a limited set of tones is the starting point for melodies, which in turn are arranged into complex structures to create symphonies. Think of an orchestra, where each instrument plays a relatively simple series of tones. Only when combined do these tones become the complex sound we call classical music. Essentially, music is just one example of a hierarchical system, where patterns are nested within larger patterns — similar to the way words form sentences, then chapters and eventually a novel.

Composers have exploited the concept of hierarchies for thousands of years, perhaps unknowingly, but only recently have these systems been understood mathematically. This
maths shows that the principles of musical composition are shared by many seemingly diverse hierarchical systems, suggesting many exciting avenues to explore. From the basic physics of string theory to complex biological materials, different functions arise from a small number of universal building blocks. I call this the universality-diversity-paradigm.

Nature uses this paradigm to design its materials, creating new functions via novel structures, built using existing building blocks rather than fresh ones. Yet through the ages humans have relied on a totally different approach to construct our world, introducing a new building block, or material, when a new function is required.

It is not the building block itself that is limiting our ability to create better, more durable or stronger materials, but rather our inability to control the way these building blocks are arranged. To overcome this limitation, I am trying to design new materials in a similar way to nature. In my lab we are using the hidden structures of music to create artificial materials such as designer silks and other materials for medical and engineering applications. We want to find out if we can reformulate the design of a material using the concept of tones, melodies and rhythms.

Our brains have a natural capacity for dealing with the hierarchical structure of music, a talent that may unlock a greater creative potential for understanding and designing artificial materials. For example, in recent work we designed different sequences of amino acids based on naturally occurring ones, introducing variations to create our own materials with better properties. However, the way in which the different sequences of amino acids interact to form fibres is largely a mystery and is difficult to observe in an experiment. To gain more understanding, we translated the process by which sequences of amino acids are spun into silk fibres into musical compositions.

In this translation from silk to music, we replaced the protein’s building blocks (sequences
of amino acids) with corresponding musical building blocks (tones and melody). As the music was played, we could “listen” to the amino acid sequences we had designed, and deduce how certain qualities of the material, such as its mechanical strength, appear in the musical space.

Listening to the music improved our understanding of the mechanism by which the chains of amino acids interact to form a material during the silk-spinning process. The chains of amino acids that formed silk fibres of poor quality, for example, translated into music that was aggressive and harsh, while the ones that formed better fibres sounded softer and more fluid, as they were derived from a more interwoven network. In future work we hope to improve the design of the silk by enhancing those musical qualities that reflect better properties — that is, to emphasise softer, more fluid and interwoven melodies.

*string theory ひも理論

(1) 下線部(1)を和訳しなさい。

(2) 下線部(2)が指している内容を、本文の主旨に照らして日本語 30〜50 字で述べなさい（句読点を含む）。

(3) 下線部(3)を和訳しなさい。