



Learning from nature for healthcare, energy, and environment

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Have you ever looked into the sky and wondered why birds could fly? Or perhaps why the leaves of cacti are needle-like? Throughout evolution, organisms have experimented with various forms and functions for over 3 billion years before the first human manipulations of stone, bone, and antler. From animal teeth to spears, fish fins to paddles, human beings have studied nature not only to satisfy curiosity but, more importantly, to learn from it for innovations and inventions. Along with the development of technology, our understanding of the creatures in nature goes beyond the pure observation of morphology to investigate exquisite composition and knowledge of fundamentals of their unique functions. Nowadays, people draw inspiration from nature to create shark skin swimsuits that increase swimming speeds, buzzard-inspired flaps that improve aircraft maneuver, and self-cleaning clothes that mimic the surface wettability of lotus leaves. These ideas are bio-inspired strategies, aiming to inspire biological methods and natural approaches to design modern technology or resolve engineering problems.

As the technology evolution involves more and more consideration of complicated system-wide factors and nonlinear engineering relationships, the pace of innovation in new science and engineering has been slowed down. When the old way of development based on violent energy consumption and unreasonable urbanization is severely challenged, as the excessive disasters we were faced within 2020, the human civilization calls for innovation in science and engineering for sustainable development. Therefore, the scientific community demands new methodologies to guide future directions. In this respect, bio-inspired strategies suggest a new approach to science and technologies based on a participatory and holistic world view informed by science, ethics, and the trans-disciplinary integration of multiple perspectives. Nature's wisdom is endless, and we have successfully solved numerous problems by using technology guided by the bio-inspired strategy. Herein, the question is: What future challenges can we address by using bio-inspired strategies?

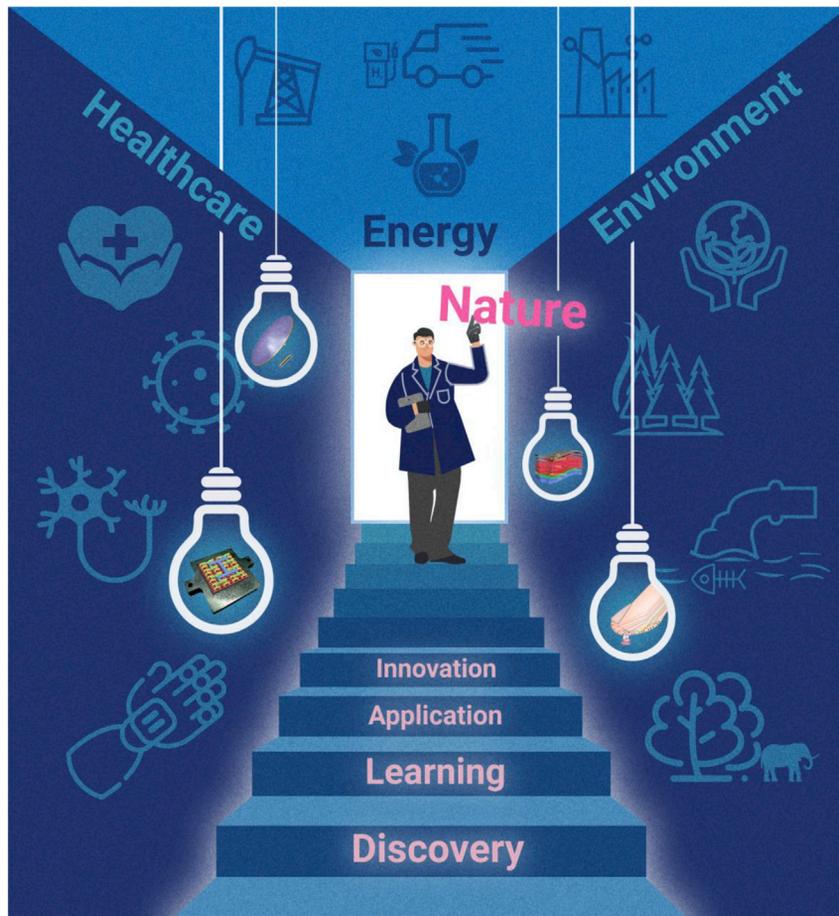


Figure 1. Learning from nature for healthcare, energy, and environment Bio-inspired strategies have made a vital contribution to address the challenges in healthcare, energy, and environment, and promise a bright future for the development of science and technology in modern society.

BIO-INSPIRED STRATEGIES FOR PERSONALIZED HEALTHCARE

Personalized healthcare is an effective method to access personal health status continuously. It is primarily shadowed by the lack of affordable wearable bioelectronics for continuous physiological information monitoring. Meanwhile, with the development of artificial intelligence, deep learning inspired by the neural network is playing an increasingly important role in healthcare, which has raised more challenging requirements for electronic devices. Fortunately, various living organisms provide us with valuable cues to resolve the challenges of endowing wearable bioelectronics with unimaginable functionalities. For example, inspired by the human epidermis, researchers focused on overlapped receptive fields and the arborization of the peripheral neurons to develop artificial peripheral nervous systems with super-high sensitivity, which reveals the flexibility of bio-inspired strategies.¹ Moreover, to perceive subtle signal changes and achieve fast signal transmission, a human eardrum-inspired sensor that demonstrated superior sensitivity with fast response time was fabricated.² In this way, scientists could develop ideas to design advanced technologies via bio-inspired strategies, making our lives more healthy, convenient, and comfortable. For instance, mechanical mismatched prosthetic limbs directly attached to the human body may cause pain and infection. To address this issue, investigators discovered how creatures deal with such problems: the squid beak can connect the soft body without interfacial damage owing to the distribution of gradient hardness. Thus, by investigating the connection mechanism of squid beaks, is it possible to develop a similar bionic therapeutic device to promote the wearability of prosthetic limbs? The flourishing development of multifunctional wearable bioelectronics cannot be achieved without the beneficial role of nature, which provides continuous inspiration in material innovation, structural design, and functionality discovery. As the main focus of consumers shifted from the pure functionality of products to a comprehensive demand combining broader applicability and convenience, the bio-inspired strategy is again on the brink of a breakthrough.

BIO-INSPIRED STRATEGIES FOR SUSTAINABLE ENERGY FUTURE

Nowadays, problems associated with energy crises are becoming increasingly severe stumbling blocks for the sustainable development of human civilization. Besides replacing fossil fuel with renewable energy sources, sustainable energy development involves two significant technological changes, including energy savings on-demand and efficiency improvements in energy production. However, current optimization problems in sustainable energy systems are becoming more complicated due to the high integration trend and systematic nonlinear design conditions, which have brought unprecedented difficulties to traditional research methods. On the other hand, living nature has gained incredible experience in the decisive energy front for survival in evolution. From the nutrition delivery in the smallest cell environment to the energy flow in the largest earth biosphere, a broad spectrum of energy technologies have managed incredible energy efficiency and optimal balance with the surrounding world. Therefore, learning from nature definitely offers us a more heuristic and effective strategy to achieve sustainability. Another innovation toward energy efficiency improvement, inspired by nature, is the bio-inspired design of fuel cells.³ The lung's fractal geometry is used as the model to design flow fields of different branching generations, resulting in uniform reactant distribution across the whole system's electrodes and minimum entropy production.

BIO-INSPIRED STRATEGIES FOR AN ECO-FRIENDLY ENVIRONMENT

The nature-inspired technologies that maintain life on earth in harmony could shape our fragile system in a perfect balance based on high efficiency and unique design. The advent of bio-inspired strategies will also bring infinite opportunities for re-balancing the relationship between technology

evolution and the natural world, thereby providing practical solutions to the emerging environmental severe issues. As the most compelling renewable energy-harvesting technology, solar cells had been shadowed by their long-term operation stability, especially perovskite solar cells. To tackle the problems, researchers developed a bionic interface layer to control the crystallization accurately and acts as an adhesive, which is an inspiration from the biological crystallization and flexible structure of vertebrae.⁴ With nature-inspired technologies, solar cells could be integrated into tiny devices, and power diversified electronics for daily usage. In addition, the bio-inspired designs could not only be inspired by single species of nature creatures but also learn from a complete ecosystem. For example, rainforests have barren soil, yet they have highly developed ecosystems with extensive biodiversity and splendid stability due to their unique closed-loop systems.⁵ When it comes to the future design of urban civilizations' infrastructure and industrial production, it is reasonable to suggest that humanity learns from natural formulation to create coordinated municipal constructions that can demonstrate eco-friendly resource cycling properties.

CONCLUDING REMARKS

Nowadays, nature-inspired technologies play an increasingly important role in developing a more sustainable world with healthier lifestyle, cleaner energy, and a better relationship with the environment (Figure 1). Faced with the severe dilemma between human civilization and nature, such as the COVID-19 pandemic, the increasing petroleum prices, or the spreading of bushfires, nature-inspired technologies can play a crucial role. Derived from living creatures, bio-inspired organs and protective devices maintain better functionality and compatibility, promising to help develop an individualized epidemic prevention system with better healthcare. Similarly, nature also inspires innovations in building a sustainable energy future, where high integration and systematic nonlinear design conditions pervasively exist.

However, the application of nature-inspired strategies comes with challenges. Without an in-depth understanding of the fundamental nature principle or that the precision of manipulation fails to reach the nanoscale, the impact of bio-inspired strategy will be significantly reduced. Another challenge lies in the impact of the unique research logic and methods of bio-inspired technology on the existing scientific and engineering fields. Therefore, a critical rule we should remember is that the development of bio-inspired strategies is always combined tightly with fundamental sciences, e.g., biology, chemistry, particle physics, quantum science, neuroscience, and so on. With an in-depth understanding of natural laws, more and more previously unimaginable bionics applications will gradually step into our living. In the future, we will see bionic scientific advancements flourish in various fields of science and technology to build up a harmonious and sustainable relationship between human society and living nature. When human beings encounter imminent problems of vital importance, it is feasible to turn to nature for solutions, because the most advanced technological ideas usually originate from the vast natural world.

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DECLARATION OF INTERESTS

The authors declare no competing interests.