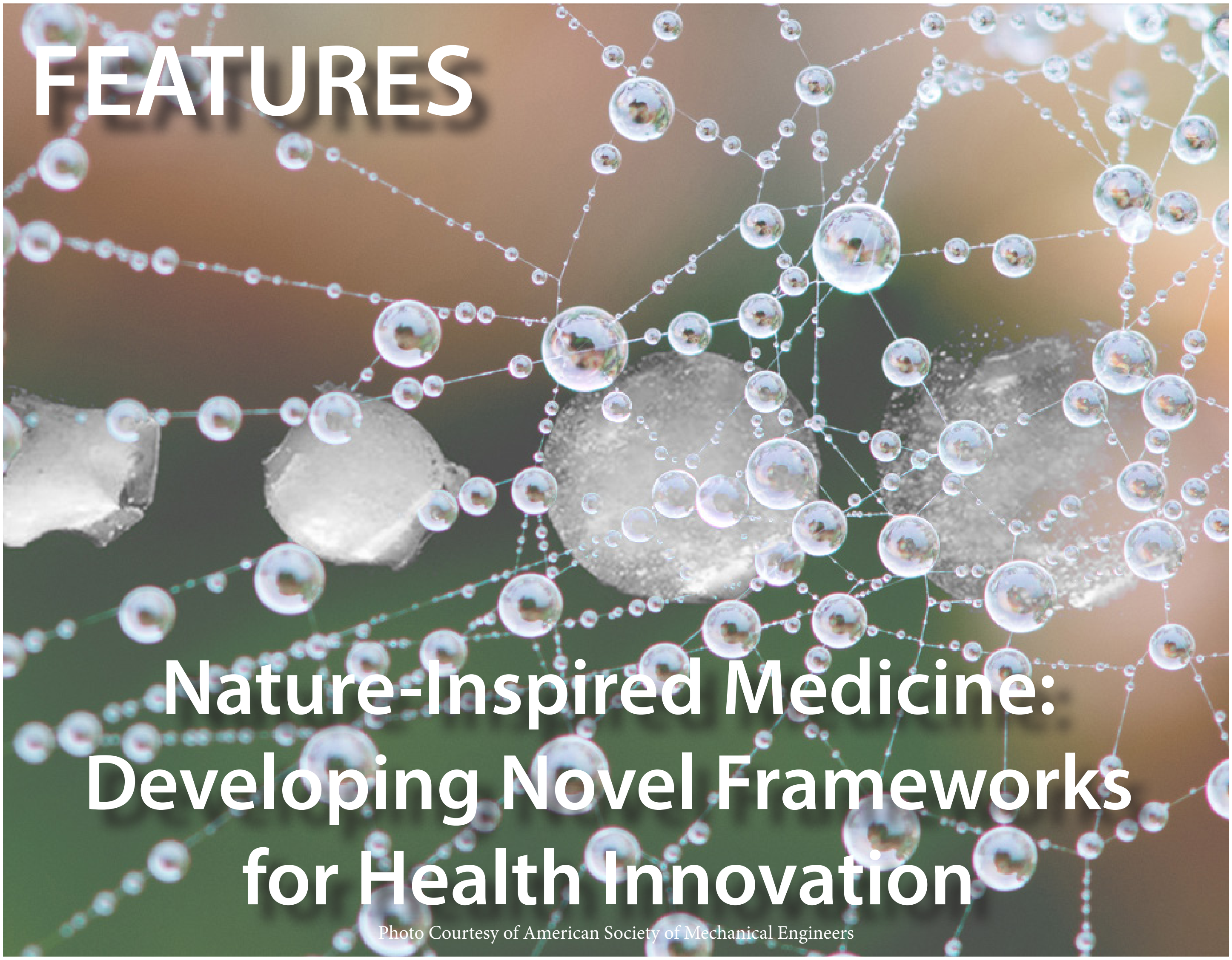

Nature-Inspired Medicine: Developing Novel Frameworks for Health Innovation

Photo Courtesy of American Society of Mechanical Engineers

Shivi Srikanth '26

The Current State of Biomedicine

From prosthetics to gene therapies, biomedical researchers have long sought to develop novel solutions to human health challenges. However, in the United States, an aging population, increased chronic illness, and contractions in research funding are placing an increasing burden on the healthcare system (Mokdad et al., 2018; Moses et al., 2015). In 2024, national healthcare use rose by 8.2 percent, exceeding the GDP growth rate by three percentage points and surpassing $5 trillion in spending (Keehan et al., 2025). With such high demand, research institutions and pharmaceutical companies are struggling to address translational bottlenecks, as well as issues of scale and sustainability.

The largest disconnect in medical research is the "benchtop-to-bedside" gap—a lack of translatability from innovation to clinical deployment—partly due to an emphasis on novelty over applicability (Woolf, 2008). According to the National Institutes of Health, 80–90 percent of studies are abandoned before clinical trials (Woolf, 2008). Furthermore, large sums of funding are funneled towards technologies that never reach patients (Seyhan, 2019). This inefficiency is described by Eroom's Law, which states that the cost of developing a new therapeutic doubles every nine years, while production efficiency halves (Scannell et al., 2012). At this rate, economists predict that the pharmaceutical industry will spend over $16 billion to develop a single therapeutic by 2043, compared to the $2.6 billion development cost often cited today (Seyhan, 2019). This trend forces the industry to produce only the most profitable drugs, favoring wealthier markets and neglecting critical disease burdens like bacterial pneumonia, which is the greatest infectious cause of death in children worldwide (Impact Global Health, 2025).

The benchtop-to-bedside gap is not the only hurdle that the biomedical industry faces. In the last few decades, antibiotic resistance, shrinking insurance coverage, and disease heterogeneity have intensified (CDC, 2019; Trosman et al., 2015). These shifts in pathology are intensified by climate change, driving demand for environmentally-conscious medicine (Romanello et al., 2024). This strain on healthcare indicates that conventional frameworks for innovation are becoming insufficient amid growing social and biological complexity.

As a response, global health researchers and agencies have turned to nature as a purveyor of healthcare, seeking answers in complex ecosystems and organisms designed over millennia. Earlier this year, the World Health Organization published a report urging widespread adoption of nature-based solutions across the healthcare supply chain as a strategy for disease prevention (WHO, 2025). Nature-based design has the potential to address deficiencies in biotechnology, laying a foundation for scalable, translational solutions and resource-conscious development.

Fundamentals of Nature-Inspiration

For centuries, societies have drawn inspiration from nature to design effective products and systems. From plant fibers for textiles to homes resembling termite mounds for passive cooling, communities across the globe have built close partnerships with the tree canopies and rapid streams around them (AlAli et al., 2023).

"Beyond reorienting the role of humans in the environmental context, nature-inspired design can leverage the intrinsic efficiency of ecosystems."

In recent years, however, humans have experienced an epistemic disconnection from nature, yielding a decline in emotional well-being and a lack of stewardship towards the environment. A 2002 study found that British schoolchildren more accurately recognized Pokémon characters than common wildlife, consistent with evidence suggesting that people in high-income countries spend over 85 percent of their time indoors (Balmford, 2002; Klepeis et al., 2001).

Scholars have posited various reasons for this disconnection from nature, the most relevant being cognitive and philosophical. Cognitive disconnection suggests that a lack of ecological education and time away from nature-centric lifestyles has caused many to forget how to live in harmony with the land (Beery et al., 2023). Philosophical disconnection points to a divergence between humans and nature due to advances in modern technology (Beery et al., 2023). This dispossession of the human condition from its ecological context has created systems that fail to protect nature from climate change and humans from its related health impacts.

To address these failures, nature-inspired design blurs the stark line between natural and built environments and encourages consumers to evaluate their impact upon planetary health (Whitburn et al., 2019). Conversely, exposure to green spaces is associated with decreased mortality and improved cardiovascular health (Twohig-Bennett & Jones, 2018). While not a direct replacement for being outdoors, grass-inspired flooring, curtains that mimic tree cover, and sun lamps reintroduce nature into everyday life.

Beyond reorienting the role of humans in the environmental context, nature-inspired design can leverage the intrinsic efficiency of ecosystems. For example, researchers at Sorbonne University recently developed wind turbine blades based on insect wing geometries, increasing energy conversion efficiency by 35 percent (Cognet et al., 2017). Furthermore, nature-based solutions push scientists to consider a product's entire lifecycle, avoiding resource waste and environmental mismanagement. This is commonly seen in green fashion companies that use plant-based dyes for clothing, abandoning petrochemicals to ensure ethical sourcing and ease of disposal (United Nations Environment Programme, 2023).

Biomedicine and Nature: Past, Present, and Future

In medicine, nature-inspired design offers yet another dimension of benefit: biocompatibility. For products that require integration into the body, harnessing chemical compounds and physical mechanisms that have proven successful in the natural world can simplify translation from laboratory to patient (Joyce et al., 2021). Many cultures have implemented natural principles for health. Among Indigenous peoples such as the Koasati, willow bark has been used for pain relief for millenia—now understood to contain salicin, a close precursor to aspirin (Mahdi et al., 2006; Taylor, 1940). Similarly, in South Africa, the Zulu and Xhosa peoples pioneered the use of aloe vera to facilitate rapid healing and soothe burns

(Fisher et al., 2025). Across South Asia, traditions like Ayurveda have leveraged the antiseptic properties of neem oil to shield against infection (National Research Council Panel on Neem, 1992).

These are generally proven approaches, but relying solely on nature-first fundamentals is unrealistic in Western medicine, where technological interventions for health are widespread and lucrative. Federal agencies like the Food & Drug Administration require strict adherence to clinical trial standards and distribution laws and are unlikely to accept cultural knowledge as an evidentiary basis (Food and Drug Administration, 2016). Furthermore, medical innovation in the United States is heavily influenced by a "technological imperative," described by sociologists as persistent pressure to use available technology once it exists (Tymstra, 1989).

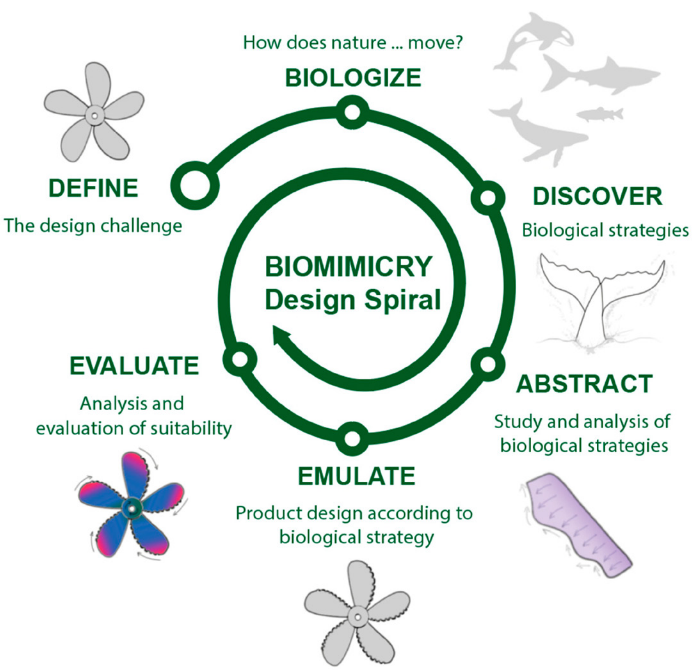

Figure 1. The Biomimicry Spiral. *Reprinted from Aguilar-Planet & Peralta (2024).*

Nature-inspired biomedicine, which retains the integrity of modern medicine and emphasizes an ecological underpinning, offers a compromise.

In some cases, stumbling upon ecological phenomena can lead to novel medical solutions. A classical example is the zebrafish, whose observed regenerative properties launched an entire field of tissue engineering to treat patient-specific disease (Gemberling et al., 2013). However, in the absence of standardized norms to guide sustainable and scalable interventions, it may not be sufficient to rely on chance alone.

To move beyond isolated efforts, frameworks for applying nature-inspired design are gaining traction. The Biomimicry Spiral, as seen in Figure 1, is a tool built by the Biomimicry Institute. Together, the six steps offer a pathway that mirrors standard engineering workflows, while prioritizing ecological considerations at critical junctures (Biomimicry Institute, 2025). Perhaps most dissimilar to standard design models is the "Biologize" function, which pushes researchers to reframe their design question entirely in organismic terms (Biomimicry Institute, 2025).

The gecko is a common model organism in nature-inspired design. Its ability to adhere to vertical surfaces, often regardless of material, has inspired skin-friendly, solvent-free adhesives for wearable devices (Kang et al., 2021). A researcher seeking to design biocompatible bandages might use the "Biologize" function of the Spiral to consider how animals with adhesive properties attach robustly to soft, irregular surfaces. During the "Discover" step, the researcher consults with ecologists to identify natural models that address these challenges and distill the strategies that ensure their success. This knowledge-gathering might uncover the gecko's microscopic underfoot scales as a promising parallel. During the "Abstract" step, the researcher identifies the material and physical properties present in the gecko, like van der Waals force maximization (Kang et al., 2021). The "Emulate" step encourages recapitulation of these properties in novel materials, such as polymer films patterned with microarrays that mimic this underfoot structure and function (Kang et al., 2021). To "Evaluate", the researcher tests the validity of this technology against its original design goals, ensuring successful translation first from organism to product, then from product to patient.

Projects that abide by the Biomimicry Spiral can be compared across similar criteria, where explicit parameters allow different labs to run the same assays and build a shared evidence base instead of producing isolated prototypes. A common framework for sustainable and biocompatible design can drive scalability and an interconnectedness not just between nature and innovation, but between institutions (Damschroder et al., 2009).

Moving Forward: Implementation and Ethics

Nature-inspired design addresses a diverse set of research challenges, making it an attractive framework to adopt. However, implementation poses a substantive hurdle. Short R&D funding cycles hinder long-term, future-facing innovation, and disciplinary silos make interaction between biomedical researchers and ecologists minimal (Franssen et al., 2018; Manlove et al., 2016).

Despite these structural barriers in the pharmaceutical sector and widespread polarization around climate change, sustainability is becoming an undercurrent in biomedicine (Kennedy & Tyson, 2024). In 2024, nearly 500 U.S. hospitals reported cutting about 185,000 metric tons of emissions, signaling a shift in environmental awareness (Practice GreenHealth, 2025). In addition, the medical biomimetics market is projected to grow by 7.6 percent between 2024 and 2030, suggesting increased receptiveness to the adoption of nature-based strategies (Grandview Research, 2024).

Moving forward, the value of this framework is dependent upon the ethics that govern it. Some scholars argue that nature-based design has the potential to perpetuate systems of extraction and exploitation of Indigenous medical knowledge for Western benefit (Alum, 2024). In 1997, the South African Council for Scientific and Industrial Research patented an appetite-suppressant from a cactus-like succulent (*Hoodia gordonii*), using knowledge long held by indigenous San communities without explicit permission. The Council only negotiated a benefit-sharing agreement, which provided credit and a share of the profits, following years of public pressure (Vermeylen, 2007). In response to cases like these, a 2024 treaty adopted by the World Intellectual Property Organization requires patent applicants to disclose inspiration drawn from indigenous knowledge in an attempt to deter biopiracy and boost accountability (World Intellectual Property Organization, 2024). However, while this treaty signals increasing support for conscious innovation, the United States and United Kingdom—two large patent producers—have yet to sign it.

With this context, any implementation of nature-inspired solutions should not be separated from local impacts. For example, the "Biologize" step of the Biomimicry Spiral must emphasize cultural context alongside function, so that models and materials are codesigned with communities whose knowledge precedes modern medicine. Preventing the extraction of Indigenous knowledge requires that explicit consent, attribution, and benefit-sharing be built into solutions at the moment of conception (Alum, 2024). Nature-inspired design has the potential to rectify inefficiencies within biomedicine and prioritize sustainability ahead of innovation, but only if wielded with legislative guardrails and humility towards the people and ecosystems who have pioneered it.

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