THE SHARK'S PAINTBRUSH

BIOMIMICRY AND HOW NATURE IS INSPIRING INNOVATION

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Introduction

THE NATURE OF INNOVATION

Why does the bumblebee have better aerodynamics than a 747?

How can a seashell keep a microchip from overheating?

How can the colors of a butterfly's wing reduce the world's lighting energy bill by 80 percent?

How can fleas' knees and bees' shoulders help scientists formulate a near-perfect rubber?

How will the answers to these and similar questions forever change our lives?

Most young ladies sunning by the pool or beach probably aren't thinking about a hippopotamus, let alone its perspiration. However, it turns out that hippo sweat provides a highly effective, four-in-one sunblock. We humans perspire by allowing salt water to leave our pores, using the physics of evaporation to cool the skin. Hippos—long-lost cousins of whales and dolphins—solve more than just a cooling problem by secreting a blend of chemicals that takes care of many challenges simultaneously. Besides being an excellent, nontoxic sunscreen (though perhaps a little aromatic in its natural form), hippo sweat is also antiseptic, insect repelling, and antifungal.

Researchers at Kyoto Pharmaceutical University and the University of Trieste, as well as Dr. Christopher Viney and his materials engineering team at the University of California, Merced, have studied the rustcolored combination of mucus and chemicals secreted by hippos. They found two pigments that absorb light across the ultraviolet-visible range, with crystalline structures that ensure the material spreads over the entire skin without the need for being rubbed on by hand (a challenge for a hippo). The pigments turn white skin a shade darker, while simultaneously slowing the rate of bacteria growth.

With one million Americans developing skin cancers each year, the market for sunscreen is substantial—$640 million a year and growing. Yet of the more than eighteen hundred products containing sunscreen on the market today, three out of four have been shown not to live up to their claims. In addition, most chemicals applied to the skin can be absorbed straight into the bloodstream, so some scientists are concerned that certain sunscreens may prevent sunburn but introduce toxins that can still cause cancer. In fact, the FDA recently responded to concerns about product efficacy by tightening the rules for sunscreen labels.

Of course, few bathing beauties would find delight in smelling like a hippo's armpit, so there's the exciting opportunity to synthesize the sweat's beneficial properties, having it smell more like, say, coconuts. Longer term, scientists anticipate applying the hippo's chemistry to exterior paints, clothing, and other UV-sensitive products.

Whether finding inspiration on hippos to reduce skin cancer or developing better road systems by studying the tracks made by slime molds seeking food, biomimicry, or bio-inspiration as some call it, very simply means applying lessons learned from nature to solve human problems. Examples of biomimicry include everything from energy-producing solar cells that mimic tree leaves to lifesaving pharmaceutical breakthroughs based on the biology of lizards to antibacterial paints that emulate sharkskin to highly profitable businesses that improve their organizational structures based on redwood groves. Even the Velcro you undoubtedly have somewhere in your closet is a prime example of biomimicry in action.

Why do we need biomimicry right now? Despite the confusing claims and counterclaims of scientists, corporations, interest groups, and politicians about whether the earth is in catastrophic decline, we all know in our hearts that something is not right. Half of all humans live on less than $2.50 per day. Fuel prices are unstable. Weather is rapidly growing more severe and unpredictable. We're living through a mass extinction of species. In the wake of the worldwide financial meltdown, innovation has slowed. In medicine, we're losing battles with antibiotic-resistant strains of bacteria, while the incidence of cancer, Alzheimer's, autism, and diabetes is escalating. And, despite living in a period with more trained researchers, engineers, and doctors than in all of history combined, the future viability of our race is in increasing danger.

The story doesn't need to end this way. Most of our environmental and economic problems result from an out-of-date way of doing business. Industry has continued to depend on the same old "heat, beat, and treat" methods that were mechanized in the industrial revolution, but these methods simply aren't sustainable. Nature, on the other hand, constantly evolves, survives, and thrives, while not using up or endangering its base resources. It reinvents itself, adapting and beginning anew with irrepressible optimism.

As a serial entrepreneur and inventor, I've spent the past thirty years starting and growing multimillion-dollar research and manufacturing companies that develop, patent, and license innovative products, ranging from prize-winning watercraft to interlocking building bricks to electronic information systems and noninvasive technology for measuring blood glucose and other electrolytes. Now I find myself credited with being among the first scientists to make biomimicry a cornerstone of modern and future engineering. My latest ventures—PAX Scientific and its subsidiary companies—design more-energy-efficient industrial equipment, including refrigeration, turbines, fans, mixer systems, and pumps based on nature's fluid flow geometries.

Simply stated, I'm on a mission to halve the world's energy use and greenhouse gas emissions through biomimicry and the elimination of waste. I'm also on a mission to inspire others to climb on board a new wave of possibility and optimism that is rapidly gaining momentum: All over the world, across dozens of industries, people are finding profitable solutions to seemingly intractable problems by partnering with nature. This book will clearly demonstrate that nature is the best source of answers to the technological, biological, and design challenges that we face as humans.

Scientists have already identified more than two million species of life on earth; some estimate that there may be as many as one hundred million. Each one has evolved hundreds of optimized solutions to life's challenges, many of which can be readily applied to the very problems facing human enterprise and survival. By constantly creating conditions conducive to life, with zero waste and a balanced use of resources, nature is clean, green, and sustainable. Following nature's design mastery, we *can* achieve greater wealth and economic sustainability. We can do this without sacrifice, while protecting our planet. How biomimicry is invigorating current business models, and how individuals and companies can reap the rewards that this burgeoning industry has to offer, is exactly what this book is all about.

Looking back, I had long shown the makings of a biomimic. When I was a boy growing up in Australia, I knew that fish were highly effective swimmers. They usually survived my admittedly ungainly attempts to catch them with a spear that I'd made from a broomstick and bent nails. Hoping to paddle farther out to good fishing sites without getting tired, I experimented with hammering the sides and bottom of my homemade metal canoe into the shapes I'd seen on fish and ducks. Of course, my canoe became easier to paddle, though I'm not sure if that could have been empirically measured or just seemed that way to my biased enthusiasm.

Regardless of efficacy, I was captivated and convinced that I was on the right path. These observations and experiments launched me into a lifelong career, first as a naturalist, observing nature's exquisitely evolved shapes, and later as an inventor, adapting those shapes to design more efficient industrial devices. During the first half of my business career, I built and sold award-winning products and companies in Australia, the United Kingdom, and the United States, but it wasn't until the late 1990s that I realized I was part of an emerging scientific discipline.

From the Greek *bios*, meaning "life," and *mimesis*, "to imitate," the term *biomimicry* was first coined in 1997 by Janine Benyus, the gifted naturalist, educator, and author of the landmark book *Biomimicry*. But biomimicry isn't new. Humans have copied nature for millennia, with varying degrees of accuracy and understanding. Our early human ancestors borrowed solutions from the animals and plants they saw around them. Seals swimming below arctic ice create and maintain holes through which they can surface to breathe; Inuit hunters mimicked the way polar bears lie in wait beside those breathing holes to catch a rich, blubber dinner. Polynesian outrigger canoes' design echoed that of floating seed pods. Aboriginal Australians even mimicked bird wings with their boomerangs. Certain shapes and tools were repeated around the world, created by people who were separated by vast geographical distances yet simultaneously immersed in and observing nature's problem-solving strategies.

Within just a few thousand years—a millisecond in evolutionary time—humans had developed much more complex tools, and the intellectual theories to support them. Newtonian physics, the industrial revolution, and the nineteenth century age of enlightenment spurred tremendous technological development and transformed our social mores. A consequence of this paradigm shift, however, was that humanity's view of the world changed from an organic to a mechanistic one. Early engineers saw the potential of breaking up any system into components and rearranging the parts. Innovations in machinery and materials led to mass production: making thousands and then millions of exactly the same forms out of flat metal plates and square building blocks. However, for all its positive impact on the economics and culture of the era, the industrial revolution's orientation was shortsighted. In the rush to understand the world as a clockwork mechanism of discrete components, nature's design genius was left behind—and with it the blueprints for natural, nontoxic, streamlined efficiency. A new set of values emerged, such that anything drawn from nature was dismissed as primitive in favor of human invention. Just as the pharmacology of the rain forests, known to indigenous people for millennia, has been largely lost to modern science, so too were the simple rules of natural design obfuscated. As our societies became more urban, we went from living and working in nature and being intimately connected with its systems, to viewing nature as a mere warehouse (some might say, whorehouse) of raw materials waiting to be plundered for industrial development.

The industrial revolution was also about cheap and plentiful power. If you needed more speed, you didn't look to nature to find a more efficient way, you just shoveled in more fuel and blasted your way forward. That approach worked well enough until the side effects began mounting: polluted air and water, stripped lands, diminishing access to cheap fossil fuel, new public health risks, and global warming.

Nature works on an entirely different principle. Its mandate for survival is to use the least amount of material and energy to get the job done—the job being to survive and re-create itself without damaging its foundational ecosystem. It doesn't stamp out flat plates; it doesn't create straight lines. For example, the ultraefficient human cardiovascular system has sixty thousand miles of plumbing, yet there's not a straight pipe inside. However, it is beyond compare when it comes to energy efficiency. How many machines can drive anything sixty thousand miles on one-and-a-half watts of power? That's less than the power consumed by many bedroom night-lights.

Given the mounting side effects of our wasteful use of energy, the imperative and opportunity to create a new global economy is upon us. We must leap into a new business and technology model or go the way of the dinosaurs. The opportunity starts with embracing nature's phenomenal efficiency and functionality. From nature's point of view, there is no energy shortage—never has been and never will be. Our whole universe and everything in it is made of energy. In nature, survival of a species depends on its optimal use of energy. If we study and faithfully copy nature's strategies for energy use, we can avert the developed world's escalating energy crisis—a crisis that is already entrenched for two-thirds of the earth's people. After life's 3.8 billion years of trial and error, experimentation, and a limitless research budget, the time has come for us to turn to nature's vast library of elegant, efficient methodologies, freely available to those who ask the right questions.

In the first part of this book—A New Golden Age—I'll introduce the tremendous potential for modern biomimicry. In one study of worldwide patent databases, bio-inspired inventions grew by a factor of ninety-three between 1985 and 2005. The rate of growth has only increased since then. Some believe that the benefits offered by biomimicry are so great, compared to conventional technologies, that bio-inspired design will replace old methods completely within the next thirty years. That's a lot of opportunity, and a lot of honest money to be made for the sake of a healthier planet—and yet, few people and businesses are even aware of the term biomimicry.

The basis of biomimicry's contemporary applicability is simple and profound: If a plant or animal had an effective solution, it survived and over time became ever more adapted to its niche. Now, with the increasing sophistication of our scientific devices, we can more precisely study nature's strategies and adapt them to solve our most intractable problems.

One of the best-known examples of commercially successful biomimicry is Velcro. When hiking in the Alps in 1941, a Swiss inventor named George de Mestral became annoyed by the repeating problem of burrs sticking to his socks and his dog's fur. He looked at the annoyances under a microscope and discovered the hook-and-loop structure that became the basis for Velcro.

Modern biomimicry is far more than just copying nature's shapes. It includes systematic design and problem-solving processes, which are now being refined by scientists and engineers in universities and institutes worldwide.

The first step in any of these processes is to clearly define the challenge we're trying to solve. Then we can determine whether the problem is related to form, function, or ecosystem. Next, we ask what plant, animal, or natural process solves a similar problem most effectively. For example, engineers trying to design a camera lens with the widest viewing angle possible found inspiration in the eyes of bees, which can see an incredible five-sixths of the way, or three hundred degrees, around their heads.

The process can also work in reverse, where the exceptional strategies of a plant, animal, or ecosystem are recognized and reverse engineered. De Mestral's study of the tenacious grip of burrs on his socks is an early example of reverse engineering a natural winner, while researchers' fascination at the way geckos can hang upside down from the ceiling or climb vertical windows has now resulted in innovative adhesives and bandages.

Designs based on biomimicry offer a range of economic benefits. Because nature has carried out trillions of parallel, competitive experiments for millions of years, its successful designs are dramatically more energy efficient than the inventions we've created in the past couple of hundred years. Nature builds only with locally derived materials, so it uses little transport energy. Its designs can be less expensive to manufacture than traditional approaches, because nature doesn't waste materials. For example, the exciting new engineering frontier of nanotechnology mirrors nature's manufacturing principles by building devices one molecule at a time. This means no offcuts or excess. Nature can't afford to poison itself, either, so it creates and combines chemicals in a way that is nontoxic to its ecosystems. Green chemistry is a branch of biomimicry that uses this do-no-harm principle, to develop everything from medicines to cleaning products to industrial molecules that are safe by design. Learning from the way nature handles materials also allows one of our companies, PaxFan, to build fans that are smaller and lighter while giving higher performance. Finally, nature has methods to recycle absolutely everything that it creates. In nature's closed loop of survival on this planet, everything is a resource and everything is recycled—one of the most fundamental components of sustainability. For all these reasons, as I heard one prominent venture capitalist declare, biomimicry will be *the* business of the twenty-first century. The global force of this emerging and fascinating field is undeniable and building on all societal levels.

In the second part of this book—Biomimicry at Work—you'll meet some of the remarkable animals and plants, along with the devoted scientists and engineers, who are proving the potential for biomimicry right now. From sharks, whales, and dolphins to lizards and leeches to bees and butterflies to trees and seashells, there are thousands of species already teaching us about engineering, chemistry, materials science, fluid dynamics, nanotechnology, medical devices, and on and on. Moreover, even the remains of extinct species can inform us. Think about it—millions of living species and ten billion life-forms in the past, each with unique solutions for us to capitalize on. As a naturalist, I've had a few adventures in the wild over the years, so I'll share some of my own encounters with biomimetic movers and shakers to introduce their secrets.

The last section of the book—The Nature of Change—explores the three chief principles of running a bio-inspired business and shares some of the challenges to their successful implementation. Throughout my career, I've seen some unnatural behavior in the boardroom as well as in the engineering lab. Rather than a walk in a park, the path to commercial success has been more of a trek through a corporate jungle. Now the path is clearing and bio-inspired design is coming out of the woods. I've watched as large companies, cities, and governments take steps to invest in biomimetic innovation and learn to tread more lightly on our planet. I'll provide pointers on how to run a business—whether large or small—more biomimetically and introduce you to biomimicry career opportunities in business and science. I'll also share practical instructions on how to develop and launch bio-inspired products, including personal stories of obstacles my companies have faced and how we overcame them.

This is a very exciting time in science and technology. I am inspired daily by the potential of applying nature's lessons to design a new golden age for the earth and for humanity—a golden age that is not only possible but realistically achievable. Biomimicry will get us there. Whether you're a CEO, corporate employee, commercial manufacturer, entrepreneur, politician, small business owner, college student looking to start a company, teacher wanting to share a world of positive choices with your students, or merely someone curious about this new paradigm, my hope is that one message rings loud and clear: By learning from nature, we can create more abundant, healthy, satisfying lives for ourselves, our children, and our planet.

Notes

INTRODUCTION

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CHAPTER 1: THE NEXT INDUSTRIAL REVOLUTION

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