Replicating Success

Biomimics learn from nature's grand designs

By Kathy Witkowsky

In a vase next to her fireplace, Janine Benyus displays a peacock feather. She keeps it there for a reason most of us would appreciate: "It's gorgeous."

But when Benyus, a science educator and consultant who lives in Stevensville, Montana, south of Missoula, looks at the resplendent eye of the feather, she sees beyond its brilliant aesthetics to a quality infinitely more brilliant: its design.

Most colors are created by pigments, which absorb all the light except the color that the pigment reflects. The reflected color is what we see. But although the feather looks as multi-hued as a Monet painting, the only pigment it contains is melanin, which is brown. Those stunning blues and greens in the eye, and subtler amber and hazel tones throughout the feather? They're a result of the feather's structure.

Each feather consists of a main shaft with fringed branches attached. The fringes on the branches are made of tiny barbs that are covered with cylinders of melanin. The cylinders are connected by the protein keratin to form a lattice pattern. But the exact structure of the lattice varies from place to place on the feather, based on how many melanin cylinders there are at a given spot, and how close to each other they are. These differences affect which light waves pass through, and therefore which colors are reflected.

Because the hues are the result of the structure, instead of pigments that can oxidize, the colors never fade.

It's a perfect example, Benyus says, of the artistry and ingenuity of nature's designs. Nature achieves its purposes without harsh, expensive chemicals or excess energy, she says. It can provide answers for human design issues—if we're willing to ask the right questions. In the case of the peacock—and other organisms such as butterflies and beetles that display color based on structure—the question is, How can we create inexpensive, nontoxic, lasting color that doesn't require pigments? Cutting-edge designers who have asked that question have found answers that led to new products.

In 2000, Nissan incorporated the structural-color fiber Morphotex, named after the iridescent South American blue morpho butterfly, into the front seats of the Silvia Convertible Varietta. Morphotex fibers have no color themselves, but thanks to their varying arrangements of polyester and nylon, a Morphotex fabric can show blue, red, purple and green, depending on how light is shining on the material.

Jointly developed by Nissan, engineering-design firm Teijin Limited and Kawashima Textile Manufacturers, the fabric looks somewhat metal-like. No energy has to be spent to dye it, and it's also recyclable without the byproduct of contaminated liquid waste.

In 2002, winter-sportswear company Descente debuted skiwear—worn by the Swiss team at the Winter Olympics—that featured Morphotex.

Structural color could potentially be applied anywhere pigments are used today, and companies are beginning to experiment with its use in paints, cosmetics and textiles. "We assume that we're the technologists, that we're the engineers," says 45-year-old Benyus, who is the author of *Biomimicry: Innovation Inspired by Nature*. Benyus coined the term "biomimicry" from the Greek "bios," meaning "life," and "mimesis," meaning "imitate." She says the natural world is filled with animals, plants, even microbes, that are excellent technologists, engineers and chemists. And thanks to 3.8 billion years of natural selection—what Benyus refers to as biological "research and development"—we know that many of the organisms alive now are ones whose techniques have proved successful on a long-term basis.

Unlock their secrets, Benyus says, and they may lead to elegant designs and sustainable business practices. Biomimicry could lead to more-energy-efficient, lower-maintenance, biodegradable products. All of which would translate into greater cost-effectiveness.

"The key insight for biomimicry is that we humans are not the first to solve these problems," says Benyus, who co-founded and leads, with Montana biologist Dayna Baumeister, the Biomimicry Guild, a research, education and consulting company created in 2000. Benyus travels the world to give workshops, lectures and speeches that encourage designers and architects to turn to nature and biologists for ideas.

Biomimicry is not a new concept, of course. Airplanes are modeled on birds, the telephone receiver on the human ear. A South American water lily was the inspiration behind 19th century botanist Sir Joseph Paxton's design for London's Crystal Palace. Paxton noted that the cellulose ribs on the underside of the lily made the leaf so strong, it could bear the weight of a person—up to 300 pounds—and he adapted the pattern to create a geometric design of flexible ribs for the palace.

In 1948, Swiss inventor and naturalist George de Mestral came up with the idea for Velcro after he and his dog returned from a hike covered with burrs. De Mestral examined the burrs under a microscope and discovered that they had tiny hooks that grabbed and clung to the tiny loops in his pants' fabric. He decided to make a fastener with hooks on one side, like the burrs, and loops on the other side, like the cloth in his trousers.

In 1989, when a sports-equipment manufacturer asked Italian industrial designer Franco Lodato to develop an ice ax, he looked to nature for inspiration. The result was an ax with a textured grip inspired by sharkskin, and a curved handle inspired by a woodpecker's beak and how the bird taps into a tree. The innovations made the ax more efficient and easier to use.

More recently, Lodato—who has developed numerous consumer products and is now a chief designer for the Motorola division that designs technology and handsets for Nextel Communications—studied the tough, protective exoskeleton of lobsters and other crustaceans as he designed a new line of rugged, shock-resistant, weather-resistant phones, introduced this past December.

Crustaceans have an outer shell made with hard and soft layers of chitin combined with calcium carbonate. The layering provides a covering that protects internal organs extremely well. To achieve the same effect and protect the phone's inner workings, Lodato's design group used hard and soft layers of polymers (chemical compounds with long repeating chains of atoms) to cover the entire exterior of the phone. The layers are made with substances such as polycarbonate and Santoprene, a rubberlike plastic material.

"I normally study what is happening in nature first," says Lodato, who has a master's degree in biodesign from the European Institute of Design in Milan. "Observing how nature has resolved challenges and created simple solutions is fascinating. Natural shapes and organisms represent millions of years of evolution—and the final product is all properly done."

But too often over the past century, says Benyus, humans have concentrated on improving inventions or products that already exist instead of seeking new ideas from the natural world. We've pursued, for example, ways to improve detergent formulas instead of asking whether we really need detergents, she says.

"There's nothing wrong with improving detergents, particularly if those improvements make them more environmentally friendly, but maybe there's a better way to clean things. Humans are the only organisms that use soap, yet plants need to stay clean to accomplish photosynthesis; animals need to stay clean to prevent infection. Perhaps we should step back and say, 'How does nature stay clean?' ''

With the body of scientific knowledge growing every year, Benyus says, we have an ever-increasing ability to develop new approaches and solutions based on nature's grand designs.

Late in the 20th century, scientists and product designers began to turn more attention to the natural world, thanks in part to Benyus' *Biomimicry* book, which was published in 1997.

One of the areas they have explored is, indeed, how to keep things clean. They studied the white lotus leaf, which grows in muddy swamps but emerges so pristine and dry that it is considered a symbol of purity.

To the human eye, the leaf looks completely smooth. But on a microscopic level, it is a rough landscape. The entire surface is covered with jagged points, akin to the teeth of a saw—but much more closely spaced—that are formed by a coating of wax crystals that repels water. The combination of the wax and the roughness causes water droplets to bead up and roll off the leaf during rainstorms, and they pick up dirt along the way. That's because the rough leaf surface causes the dirt to teeter on the tips of the points. When it rains, the dirt has more contact with the water than with the leaf and is swept away by the rolling droplets.

This so-called "lotus effect" was discovered by Wilhelm Barthlott, a botanist at the University of Bonn in Germany, who in 1998 patented it under the "Lotus-Effect" trademark. Shortly afterward, ISPO, a German company, began producing a masonry-like, spray-on exterior paint, called Lotusan, that dries in a similarly rough pattern to create a coating that self-cleans in the rain. The silicone-based paint contains nanoparticles of titania that create the textured surface and repel water.

Some manufacturers are working on Lotus-Effect coatings that might lead to self-cleaning cars, and the German company BASF is developing a spray-on Lotus-Effect coating that may one day be applied to paper, leather and textiles.

The lowly Stenocara beetle in southern Africa's Namib Desert has inspired another new technology—this one for harvesting drinking water from fog.

In 2001, scientists discovered that the insect's back is covered with microscopic hydrophilic, or "water-loving," bumps. The sides of the bumps and the valleys between them have a wax coating that repels water. The tops of the bumps are not waxed.

When fog rolls in, as it does several mornings each month, the beetle puts its head down and tilts its back into the wind, and the water-loving bumps catch the precious moisture. Water collects on the bumps until the droplets grow big and heavy enough to roll down the waxy sides and into the insect's mouth.

Companies in Germany and the United Kingdom have mimicked the beetle's structure with plastic sheets covered with bumps made from tiny glass beads embedded in wax. The sheets are aiding Third World farmers in arid lands, says University of Oxford zoologist Andrew Parker, who led the team that discovered the beetle's fascinating ability.

The bug's structure may also become the basis for a new type of desert tent—one that would be able to trap ambient moisture for drinking water, he says. And one day, beetle-inspired devices may even capture, and thereby reduce, fog at airports.

Janine Benyus can point to many more natural technologies that scientists are trying to harness. Imagine, for instance, a tough-as-nails thread modeled after spider silk—which, ounce for ounce, is five times stronger than steel. A powerful, waterproof glue based on the one secreted by blue mussels to connect themselves to rocks in the ocean. Or a lightweight, fracture-resistant coating inspired by the abalone shell.

The Biomimicry Guild, which serves as a networking hub for people pursuing biomimicry, keeps a list of case studies on its Website. The guild is also creating a database to help designers find biological solutions to problems. Type in a function—say, "self-cleaning"—and up will come various strategies that nature uses, as well as links to experts and scientific literature.

Benyus' book, which has been translated into Chinese and Portuguese, has propelled her into a new role as a consultant for companies such as Nike, S.C. Johnson & Son, Patagonia and Gensler. These companies are reluctant to reveal the nature of the biomimicry projects they're working on, since it might give competitors an edge, and nondisclosure agreements keep Benyus from discussing what products or applications have resulted, but she's encouraged by the amount of corporate and academic attention biomimicry is starting to get.

She has been a guest lecturer at colleges ranging from the University of Minnesota College of Architecture and Landscape Architecture to the University of Pittsburgh School of Engineering. And she has been a keynote speaker for groups such as the

American Institute of Chemical Engineers and Kaiser Permanente, as well as for numerous environmental organizations.

Arizona State University President Michael Crow credits her book with influencing him to build a new $500 million Biodesign Institute on the ASU campus in Tempe. Construction of the institute is already under way, with the first of four buildings scheduled for completion this November. The book, he says, got him thinking: "Could we replace the crude and oftentimes environmentally negative technologies of the past with a new kind of science—the mimicking of nature?"

A major emphasis of the institute will be training and research geared toward "mimicking nature's designs and systems to enable society to create new innovations in health care, agriculture, ecology, energy and global security," he says.

And thanks to Benyus' ideas, San Francisco's California College of the Arts will require freshmen majoring in industrial design to take a course in biology, starting this fall. "We've been teaching sustainable design for years. But teaching biology in conjunction with that is brand new," says California College of the Arts associate professor Sue Redding. "It's so obvious, we almost missed it."

To make sure future generations don't miss the concept, the Biomimicry Guild has begun collaborating with the nonprofit organization Mid-continent Research for Education and Learning to find funding to develop a K-12 curriculum that addresses biomimicry. School districts in California and Montana have already expressed interest in having such a program.

Even England's Prince Charles is interested in biomimicry. In January of this year, Benyus received an e-mail from the deputy private secretary to the prince, explaining that His Royal Highness had been "riveted" by one of her speeches and wanted more information.

Benyus is happy to oblige. "I'm thrilled because I'm seeing the change of heart—this deepening of respect and awe and gratitude for the natural world." And that, she says, "is a hopeful sign in the evolution of our species."

Kathy Witkowsky lives in Missoula, Montana.
For more information on biomimicry, visit www.biomimicry.net.

Better Propellers

As a child growing up in Western Australia, Jayden Harman was fascinated by the marine life he saw while he swam, snorkeled and spearfished along the reefs there. He admired how effortlessly the fish slipped through the water. And he noticed something else: No matter how strong the current or how devastating the storm, the seaweed—specifically, the kelp—didn't get damaged. Instead, it wound into a spiral shape to create the path of least resistance.

That led to his first "aha" moment, at the age of 10. "Suddenly it occurred to me that nature uses a particular way of streamlining," recalls Harman, now 54, and the CEO of PAX Scientific, an industrial-design firm he founded in 1997 in San Rafael, California. Harman became a permanent resident of the United States in the late 1990s, after a career in Australia that included working as a naturalist for the

Australia Department of Fisheries and Wildlife, and founding a technology firm whose diverse products included active-screen billboards, plastic molding systems and afterburners for aircraft.

“An enormous amount of the energy we humans use is to overcome friction,” Harman says. “And nature overcomes friction in far more efficient ways than we do.” In nature, liquids and gases flow in a geometrically consistent, three-dimensional, centripetal swirling pattern, and natural organisms function very efficiently within that pattern, he says.

He began to wonder if he as a designer could apply those concepts. Fish, birds, plants, insects—anything that moves through fluid or moves fluid in order to survive—became potential sources of inspiration. His first biomimicry design work came in the 1980s, when he built boats with hulls based on the shapes of dolphins and fish. In the 1990s, the shapes of sea creatures such as the trochus snail, sea anemone, squid and octopus suggested a more effective shape for propellers.

“That’s our secret sauce, and we’re lucky because nobody else has accomplished it,” Harman says. “Nature is so elegant in what it does, I think: ‘Why do we put up with all of this industrial equipment that’s not really doing a good job?’ ”

For instance, large ships consume billions of dollars’ worth of fuel every year, but many ship propellers are only 40 percent to 50 percent efficient, he says, which means a lot of that fuel is wasted.

One of the reasons is that ship propellers create and suffer from “cavitation”: air bubbles formed, in part, by turbulence. Cavitation is a serious problem because it creates drag, and it can damage the propellers.

Using what he learned from the geometric shapes of creatures in the sea, Harman has designed a propeller that does not cause cavitation. “That’s very significant,” he says. “Even a small increase in the efficiency of ships could save a tremendous amount of fuel.”

Harman has patented the propeller design, along with nearly a dozen similar nature-inspired designs, for items such as fans and turbines, and mixers used to stir fluids. Effective stirring is essential in applications such as adding chemicals to water to purify it. The chemicals need to be mixed so that they dissolve evenly in the water, and because the process requires extensive stirring, energy efficiency is valuable.

One of Harman’s designs is for a domestic exhaust fan, like the one you use in your kitchen or bathroom, that he says is half as noisy and up to 75 percent more energy efficient than the ones dominating the market because its design reduces friction and requires a smaller motor.

PAX Scientific won’t release many details about its products because it has just begun to negotiate licensing agreements with manufacturers, but Harman says the list of potential applications includes any instance in which air or water is moved: computer fans, car engines and compressors, and biomedical fluids. Medications need to be stirred in a way that doesn’t introduce oxygen, which could cause a chemical reaction, he says, and cavitation can damage cells, such as red blood cells, that are being stirred.

"I love nature, and I hate waste," Harman says. "I'd have to say in every case I've ever seen, nature is still the supreme designer." *—K.W.*