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Philip A. Reed
Old Dominion University

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A PARADIGM SHIFT: BIOMIMICRY

Philip A. Reed

Biomimicry is a new way of linking the human-made world to the natural world.

We are in the midst of a paradigm shift in the way we view and interact with the natural world. This new line of thinking—biomimicry—is already having a tremendous impact on the way we design technological products and systems. It is also an excellent example of the interdisciplinary nature of science and technology, which is an extremely important component of technological literacy (ITEA, 2000).

The word biomimicry comes from the Greek words *bios* (life) and *mimesis* (imitation). In short, biomimics imitate nature. We now have the capability, however, to not only imitate the products of nature but also nature's materials and processes. The three primary areas of biomimicry include using nature as a model, a standard of measure, and as a mentor (Benyus, 1997).

History of Biomimicry

We have always had a symbiotic relationship with nature to varying degrees. Early humans lived very closely with nature because it was vital for survival. Nomads would roam because they needed to find food, shelter, and clothing. When the resources in an area were consumed, they would move on to find new resources.

Early civilizations gained limited control over nature by domesticating animals and growing their own food. However, these civilizations still lived closer to nature than we do today because they were more dependent on nature to grow crops, provide medicines, and clean up their waste.

During the seventeenth century, the relationship between humans and the natural world changed in several ways. The biggest change was when science evolved as a separate field from natural philosophy. This happened, in large part, because many natural philosophers began to *do* things, not just talk and philosophize about them. People began breaking down the complex web of systems that tie the natural world together. A classic example is William Harvey, who discovered the circulation of blood. Before Harvey documented blood circulation as a system, people had no idea what blood was used for or the relationship between the lungs, heart, and other vital organs.

Technology began to play a vital role in this new discipline because scientists started to develop instruments to investigate the natural world. These events not only changed the way we learned about the natural world, but they also changed the way we taught. Colleges up to this point focused on classical languages, reading, writing, mathematics, philosophy, and history. Soon, however, colleges began to offer many specialized courses. This is what historians call reductionism because disciplines reduced their course offerings to very specific topics. For example, instead of a course on natural philosophy, colleges began to offer specific courses on astronomy (study of the heavens), entomology (study of insects), or other specialty areas.

Biomimics, however, feel reductionism for the most part has run its course. They feel we need to step back and once again look at nature as one large, integrated web. The rationale is that we can and should be using our natural resources more wisely. They make a strong argument that is supported by some extraordinary findings and achievements.

Nature as A Model

Many products we use today are based on nature. Velcro®, for example, was created in the image of seed hooks that fasten onto objects when they brush up against them. New tools and methods, however, allow us to look deeper into nature. Scientists of various disciplines are working with engineers, designers, and other researchers in an interdisciplinary manner to create products and systems based on nature.

Nature has created many examples of what works and what does not. Many of these examples we still do not fully understand. The harnessing and use of energy is a prime example that could help solve many of the world's problems. Researchers are looking toward the process used by plants, photosynthesis, to better understand nature's energy model. Figure 1 shows a satellite covered with our current model of harnessing the sun's energy, silicon-based solar cells. Nature has found a much more efficient method to harness the sun's energy.

Observing the photosynthesis energy model has led to a significant amount of research in the area of chemically based solar cells. If the level of efficiency in plants can be achieved by using a chemical process, researchers predict four significant applications: 1) clean electrical production, 2) splitting of water to produce clean-burning hydrogen, 3) efficient power packs, and 4) high-speed switching for computing.

Nature still has many photosynthesis secrets, however. The bacterium in leaves that do the energy conversions contain thousands of reaction centers that are thirty angstroms by eighty angstroms (an angstrom is one tenth of a billionth of a meter). Despite the powerful imaging tools available to scientists, they still cannot fully understand the entire process.

A second example of nature as a model involves the development of adhesives. Researchers at major universities and chemical companies are always trying to produce better adhesives and bonding for paints. The major drawback has always been moisture that separates the adhesive from the surface material. To combat

Figure 1. Silicon-based solar cells are not even 25% efficient at converting the sun's energy into electricity, but many plants approach 95% efficiency.

moisture, we typically use primers that imitate the bonds within the surface material and provide hooks for the finish material. Moisture, however, always finds a crack and eventually breaks the adhesive bonds.

Researchers are now looking at nature's model of bonding materials in wet environments. Specifically, shellfish have the ability to form extremely tight bonds on various surfaces, sometimes in a matter of seconds (Figure 2). These bonds are created through cohesion and adhesion. Proteins produced by the shellfish form cohesive bonds with the mating surface. This actually integrates the two materials so there is not a single "weak link." However, like the example of photosynthesis, the chemical reactions are complex and still not fully understood.

A third natural model could have significant implications for agriculture. Advocates for better farming practices are attempting to create a farming model based on the methods of the prairie. The Land Institute has conducted research for over 20 years in Kansas with the purpose "to develop an agricultural system with the ecological stability of the prairie and a grain yield comparable to that from annual crops" (The Land Institute, 2003). A significant amount of The Land Institute's research did in fact demonstrate that native vegetation could share space with food crops and reduce the dependence on pesticides, herbicides, and fertilizers. By using a variety of native plants, food crops remained healthy because the soil was replenished by natural decomposition, and the diversity did not attract a concentration of pests. This example completely eliminated the need for oil-based pesticides, herbicides, and fertilizers that are expensive and often run off into the water supply.

Nature as Measure

Through its billions of years of evolution, nature has learned what works, what is appropriate, and what lasts. Large corporations are now taking this to heart by mirroring natural ecosystems. In fact, many Chief Executive Officers (CEOs) are learning about sustainable systems and survival techniques from ecologists.

The analogy between ecosystems and economic systems is uncanny. A Type I ecosystem contains plants that quickly move in, use up the resources, and then move on. An example would be the weeds that spring up in a newly plowed field. A Type II system contains perennials that are more enduring but still are not fully self-sustainable for long periods. Type III ecosystems are self-sustainable and therefore remain relatively stable for long periods. CEOs are predominantly interested in Type III ecosystems because they emulate long-term planning. Unfortunately, most businesses currently run like a Type I or Type II system, which resemble short-term business planning.

An old-growth forest provides an example of a sustainable ecosystem (Type III). The forest has learned to survive because it utilizes the ten strategies of a mature ecosystem:

1. Use waste as a resource.
2. Diversify and cooperate to fully use the habitat.
3. Gather and use energy efficiently.
4. Optimize rather than maximize.
5. Use materials sparingly.
6. Don't foul their nests.
7. Don't draw down resources.
8. Remain in balance with the biosphere.
9. Run on information.
10. Shop locally.
    (Benyus, 1997, pp. 253-254).

The strategies outlined above have been efficiently implemented in the industrial ecopark located in Kalundborg, Denmark. Four companies are located in the park, and they have created an elaborate system to integrate their resources and waste systems. In fact, the waste from one industry often enters the production methods of a neighboring industry. For example, the Asnaesverket Power Company provides waste steam to run engines at an oil refinery and pharmaceutical plant. Steam from the power plant is also used to heat 3500 homes. In addition, water that is used to cool the power plant is warmed in the process and helps maintain 57 fishponds in Denmark's cold climate.

Insulin and enzyme production at the pharmaceutical plant produce slurry that is piped to farmers for use as fertilizer. The grain grown by farmers will, in turn, be used by the pharmaceutical company to feed the bacteria. Sulfur from the power company and refinery smokestacks is used in several ways. It is either converted to calcium sulfate for a gypsum wallboard plant, or it is taken to another company that produces sulfuric acid (Graedel and Allenby, 1995).

The Kalundborg ecopark clearly demonstrates the ability to make elaborate technological systems that imitate natural systems. Other companies have been doing this on an individual scale for some time. The 3M® company, for example, began a program called 3Ps (Pollution Prevention Pays) back in the 1970s that has since altered 4,350 production processes, eliminated 1.2 billion pounds of waste, and saved an estimated $750 million.

Nature as Mentor

The philosophy that has evolved in the developed world regarding nature is two-pronged: *What can we extract from nature* and *How can we control nature*? Biomimicry, on the other

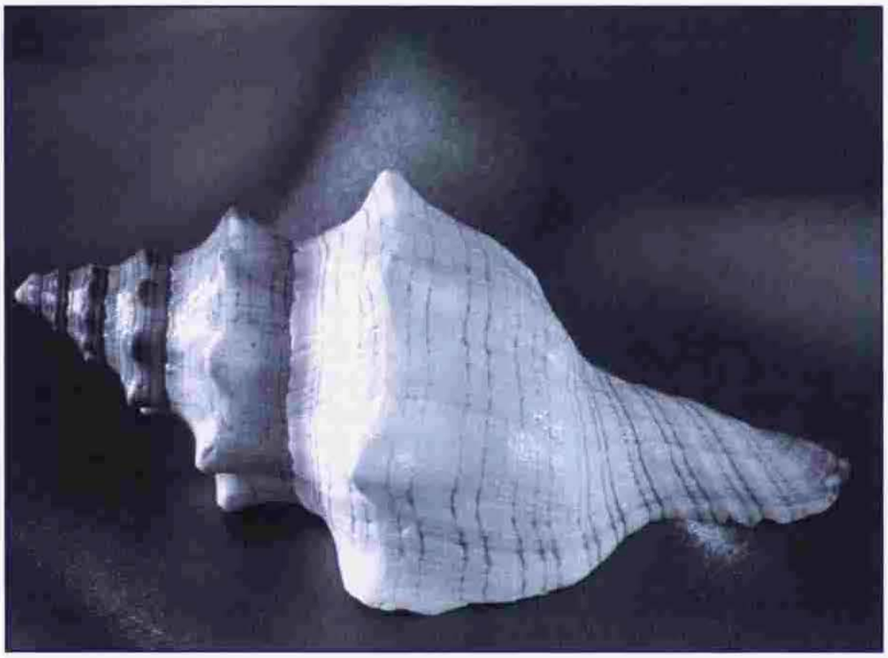

Figure 2. Shellfish are an excellent model for adhesives in wet environments because they crosslink with the mating material (cohesion) and bind to the surface (adhesion).

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hand, looks to nature as a guide. Biomimics do not focus on controlling nature, rather they want to imitate nature and even learn how to duplicate the materials and processes of nature.

Businesses and industry are starting to implement examples provided by nature. One of the most extraordinary examples is the use of organic computing. For years researchers have been fascinated with the way deoxyribonucleic acid (DNA) stores and transfers information. Researchers have found several ways in which nature processes information, and many scientists and computer engineers feel biocomputers will soon be a reality.

One of the processes already demonstrated used the four DNA bases (adenine, thymine, guanine, and cytosine) to create a code. Because adenine always pairs with thymine and guanine pairs with cytosine, computer scientists were able to arrange the bases of split DNA strands and predict how they would reassemble. Computer scientists have also used this natural DNA assembly process to solve simple problems.

A second biocomputing technology was tested by Hughes Aircraft and utilized light-sensitive bacteria. The bacteria would kink under certain light frequencies and straighten under another frequency. Engineers applied the bacteria to a sheet of glass and utilized light to simulate a computer storage device. The kinked bacteria would represent one binary state, and the straight bacteria the second binary state. The bacteria reaction times were extremely quick, and they could be arranged in a much denser pattern than the metal oxides currently used in magnetic storage systems. Researchers are now arranging the bacteria into three-dimensional cubes and utilizing multiple light sources to store data three-dimensionally (holographically).

Besides biocomputing, several other initiatives look at nature as the mentor. The United States Environmental Protection Agency (EPA) Design for the Environment program is a green manufacturing concept that promotes the integration of cleaner, cheaper, and smarter solutions into everyday practices. The EPA also supports using "benign by design" principles in the design, manufacture, and use of chemicals and chemical processes—a concept known as "green chemistry" (U.S. Environmental Protection Agency, 2003).

A third mentoring example can be shown by the military's interest in spider silk (Figure 3). The uniqueness of spider silk is in the mysterious manufacturing process. Spiders often produce multiple types of threads, but they all start with liquid proteins that are squeezed through spinnerets. During this process the silk emerges as an elastic tube that surrounds a strong chain of crystals. Researchers are trying to duplicate this process in hopes of creating bulletproof fabrics, cables for suspension bridges, artificial ligaments, sutures, and other products.

Summary

Biomimicry is a new way of linking the human-made world to the natural world. This philosophical shift returns to the pre-scientific revolution notion that all things are intimately connected. Biomimics strive to use nature as a model, a standard of measure, and as a mentor.

The "nature as a model" metaphor goes beyond designing artifacts that imitate nature. Instead, biomimics also want to duplicate the materials and processes used by nature. Because nature has evolved over billions of years, they also look at the efficiency of the system as a measuring guide. Nature is not wasteful, and cleverly chooses the path of least resistance to solve very complex problems. Many of these problems, like the way information is stored and transmitted, are still not fully understood, but researchers are looking at nature as a mentor to guide them toward a replicable model.

Biomimicry is an extremely interdisciplinary field that involves scientists, ecologists, engineers, and other specialists. The United States military, universities, business, and industry are all interested in and support research in this area. This paradigm shift is even influencing politics. In 1996 a new political party, the Green party, was formed for people who believe we should "practice agriculture which replenishes the soil, move to an energy-efficient economy, and live in ways that respect the integrity of natural systems" (Green Party of the United States, 2000).

Biomimicry will continue to influence our lives because, even as advanced as we are, we still do not know much about nature. For example, there are an estimated 5 to 30 million living species on earth, but only about 1.4 million have been named! Just imagine how much we will learn from all of the research and development nature has already performed.

Class Activity: Design for Disassembly

The country of Japan is very small compared to most industrialized nations. Because of this, the Japanese people have developed some unique methods to drastically cut down on the amount of waste from business, industry, and consumers. One idea, called "design for disassembly,"

Figure 3. Spider silk is five times stronger than steel and can withstand an impact five times greater than Kevlar. The impact absorption of a web like the one above is so great that researchers claim a web the size of a fishing net could stop a passenger plane in flight.

actually unites companies that normally compete in the same market.

Companies that use the design for disassembly concept start by thinking about a product's end-life. They plan for the recycling of parts, and competitors even form alliances to help create the channels that will be needed to reclaim parts and materials. Under this philosophy, companies work together up to the point when the marketing campaigns begin. At that point, it is business as usual!

In the United States the big three automakers, Ford, Chrysler, and General Motors, are also working with each other and trade associations to help recycle auto parts and reduce waste. Even personal computer manufacturers are getting in on the act by offering incentives to people who "trade-up" to a new computer. And Xerox estimates it saves $250 million annually by designing copiers with modular parts that can easily be exchanged and returned to the production process.

Challenge

Select a product that has multiple parts. Start with an item that has just a few parts (i.e. toaster, swing set, beach chair) and later work on a complex product (i.e. television, computer, automobile). Create a new design that considers the pre-life, useful life, *and* the end-life of your selected product. When creating your new design, assemble a portfolio that contains the following sections:

1. A clear definition of the problem.
2. Brainstorming and research notes.
3. Sketches of several possible solutions.
4. Criteria and constraints of each idea.
5. Rationale of why you chose one design over the others. Think of this section as a list of items you could use in a marketing campaign for your product.

When you are working on your design portfolio, be sure to address these essential questions:

1. Does the design use recycled materials?
2. Does the design use a minimal number of parts and materials?
3. Is this product easily assembled?
4. Can my design be quickly disassembled for upgrading, repair, or recycling?

This activity will also work well with students in small groups of two to four, especially if they select a complex product. Additional portfolio requirements might include a bill of materials, technical drawings, a model or prototype, and a marketing plan.

References

Benyus, J. M. (1997). *Biomimicry: Innovation inspired by nature.* New York, NY: HarperCollins Publishers Inc.

Graedel, T.E., & Allenby, B.R. (1995). *Industrial ecology*. New York, NY: Prentice Hall.

Green Party of The United States. (2000). *Ten key values.* Retrieved October 8, 2003, from www.gp.org/tenkey.htm.

International Technology Education Association (ITEA). (2000, 2003). *Standards for technological literacy: Content for the study of technology.* Reston, VA: Author.

The Land Institute. (2003). *About the Land Institute.* Retrieved October 8, 2003, from www.landinstitute.org/vnews/display.v/ART/2000/08/10/37a747b43.

U.S. Environmental Protection Agency. (2003). *Design for the environment.* Retrieved October 8, 2003, from www.epa.gov/opptintr/dfe/.

Philip A. Reed, Ph.D. *is an assistant professor at Old Dominion University in Norfolk, VA. He can be reached via e-mail at preed@odu.edu.*