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BIOMIMETICS AS A VEHICLE FOR LEARNING GOOD SCIENCE AND BUILDING FAITH

by

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INTRODUCTION

The purpose of this brief essay is to showcase, worship, and honor the creator God. In addition to being creative, God reveals himself to us through scripture, through nature, and through a personal relationship with him. Clearly, God wants to be known by us. And through the various media of his word, his creation, and his daily walk with us, he lets us know of his unconditional love for us and his purpose for us. God is purposeful.[1]

My faith in God was especially enhanced and strengthened recently when I happened to learn how many human inventions have simply been borrowed from the Creator's vast repertoire of designs.[2] In fact, when I began to study into it, I learned that there is a whole discipline purposefully focused on studying nature's design secrets in order to make better stuff for people. This discipline is called biomimetics. And as I studied, it began to dawn on me that this discipline of biomimetics would make a wonderful vehicle for teaching biology to my students at all levels while inviting them to build personal faith in GOD.

This essay will begin with an introduction to biomimetics and the overarching rationale of this relatively new discipline. Then several examples of biomimetic inventions will be described followed by a discussion of the problem of purpose in biology. Briefly, the problem is that mainstream biologists insist that biological systems are purposeless.[3] The elaborate systems that biologists seek to understand simply evolved by chance. Yet the irony is that biomimetic scientists are eager to learn from the so called purposeless to make highly purposeful inventions. Finally, the essay will describe one way that students can readily connect to their Creator as they discover the elaborate purposefulness of created structures. And in this connection, they discover purpose for their own lives.

BACKGROUND

My interest in designed structures all started with the fortunate juxtaposition of an old watch and an insatiable childish curiosity.

I was just five years old–long before the digital age. Using my dad's tiny screwdrivers and a pocketknife, I was able to explore the contents of the old watch to my young heart's content. The thrill of exploration and discovery was palpable. With clumsy chubby fingers, I pried off the back and removed every screw, gear, lever, and wheel. What did it look like inside? What made the hands go around? What made it tick? How did it work? I still remember the startle and the adrenalin rush when I opened one shiny little compartment and a long thin flat wire literally exploded out of the container releasing all the pent up energy of the mainspring. You guessed it. That watch never worked again.

Recently, as a still curious grandpa, I disassembled an old DVD drive from my computer simply to see how it worked. The precision and complexity of those tiny mechanical, electronic, and optical parts took my breath away. This time, I explored much further. Using the scanning electron microscope, I gazed in wonder at the elaborate canals, ridges, and dimples of the silicone wafer that was the heart of the integrated circuit in the DVD drive. How does it work? Rather, how did it work?

Despite the breath taking complexity of my never-to-run-again DVD player embodied in the hair thin wires, miniscule steel springs, ruby lasers, lenses, micro-switches, and electronic circuits, these devices don't begin to compare with the degree of miniaturization and complexity exhibited in biological systems. As a professional biologist today, I am still taking things apart – mostly living things and learning how they work. I still end up with a pile of non-functional parts. Don't laugh. Have you ever tried putting a frog back together again?

One of the reasons that I love learning about biological systems is because each structure has specific function. And I am fascinated by the abundance, diversity, elegance, and simplicity of clever design that I find. Living systems are engineering grab bags. Biologists find levers, wheels, knobs, joints, pulleys, plectrums, vibrators, oscillators, connectors, bushings, rods, pipes, conduits, valves, wires, warning signals, switches, sensors, activators, inhibitors, junctions, transporters, lubricants, glues, surfaces, wrappings, barriers, openings, and other structural mechanisms that function not only beautifully but purposefully. One of the generally accepted unifying themes of biology is "structure/function relationships". According to this unifying theme, when we analyze a biological structure, we should be able to figure out what its function is. And the opposite is true too. When we discover a function, we should be able to find an appropriate structure busily at work.

If I am to believe one of the cardinal teachings of mainstream biology however, all of these functioning structures came about by random chance. These structures that just happened by chance were put to use for various biological functions. According to biological dogma, there was no purpose that brought the structures into being. The teachings of mechanistic naturalism state that there is NO supernatural. If that is true, then all biological systems, whether simple or elegantly complex happened by chance.

How then does this naturalistic philosophical position square with the rapidly growing field of biomimetics also known as bionics? Biomimetic scientists are mostly "inventors". They carefully study biological systems in search of ideas and inspiration for new and better inventions. Biomimetic scientists carefully study "purposeless" systems so they can adapt them for use in extremely purposeful ways.

The noted guru of biomimetics, Dr. Yoseph Bar-Cohen expresses what most biologists believe to be the source of the design genius.

> "Nature evolves by responding to its needs and finding solutions that work, and most importantly, that last through innumerable generations while passing the test of survival to reach its next generation. [...] After billions of years of trial and error experiments, which turn failures to fossils, nature has created an enormous pool of effective solutions. [...] Through evolution, nature has "experimented" with various

solutions to challenges and has improved upon successful solutions. Organisms that nature created, which are capable of surviving, are not necessarily optimal for their technical performance. Effectively, all they need to do is survive long enough to reproduce. Living systems archive the evolved and accumulated information by coding it into the species' genes and passing the information from generation to generation through self-replication. Thus, through evolution, nature or biology has experimented with the principles of physics, chemistry, mechanical engineering, materials science, mobility, control, sensors, and many other fields that we recognize as science and engineering. [...] As the evolution process continues, biology has created and continues to create effective solutions that offer great models for copying or as inspiration for novel engineering methods, processes, materials, algorithms, etc."[4]

The purpose of this essay then is to open a small window into this relatively new and rapidly growing field of biomimetics. We will explore a few notable "inventions" and then try to use this knowledge in better understanding purpose or teleology.

INTRODUCTION TO BIOMIMETICS

Biomimetics[5] or Bionics[6] as it is sometimes called seeks to gather ideas or inspiration from biological systems to make useful creations.

Thanks to bioinspired designs, we enjoy many new products from Velcro®[7] (Figure 1) to radar units[8] to better aeronautics[9] to stronger superglues[10]. Besides the inventions of things, recent emphasis has focused on making the manufacturing process itself sustainable, making it function more like biological synthesis. You see, most of our manufacturing involves what Janine Benyus[11] describes as "Heat, Beat, Treat" rather than the more ecologically friendly method of building from scratch, atom-by-atom, molecule by molecule, with minimal or zero environmental waste.

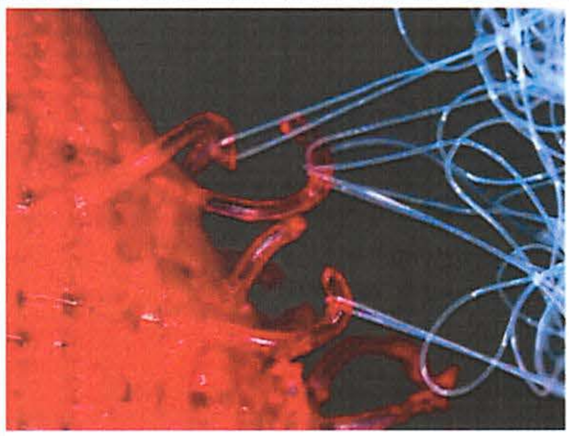
Figure 1 Velcro as viewed by a stereo microscope.
Photo by Tracy Anderson
http://photography.qj.net/category/Flickr/cid/857

Think of what it takes to make an integrated circuit, the "brains" in a computer. In Silicon Valley, the process of making the tiny silicone chip with its precise nanostructure involves heating to very high temperature, polishing, printing and etching with acids (treating)[12]. It is a very long and painstaking process. The resulting flood of toxic waste is highly carcinogenic.

An exquisitely sculpted diatom on the other hand, also made from silicone, also with exquisitely ordered nano structure is built up atom by atom, molecule by molecule in an aqueous, nontoxic solution.[13] If only we could learn to manufacture like mother nature does, we would greatly reduce the environmental impact of our manufacturing processes. That is the goal of much current biomimetic research.[14]

To make sure we understand then, the idea behind biomimetics is that nature has been "experimenting for millions of years" and has "discovered" the most efficient and useful designs. Nature has "learned" how to make these amazing systems in ecologically friendly ways. So biomimetic scientist work very hard at discovering the design secrets and the process secrets in order to make better products in environmentally friendly ways. What follows now are a few specific examples of biomimetic work to help exhibit the variety and amazing success of the work.

Radar/Sonar/Echolocation

Well before biomimetics was recognized as a good thing to do, there were examples of human engineering projects that naturally followed design concepts from nature unawares. For instance, chapter 2 of Dawkins book "The Blind Watchmaker"[15] is titled "Good Design". The centerpiece of chapter 2 is a well written, detailed and very engaging description of the highly sophisticated and finely tuned bat echolocation systems that Dawkins says would "strike an engineer dumb with admiration." Toward the end of the description Dawkins describes how electronics engineers of the day (1940) were incredulous and even indignant that the bats had already perfected this type of system. After all, radar and sonar systems of the time where still highly classified and it had taken the engineers enormous painstaking work to develop these sophisticated systems. And to think, these ugly, small, blind, nocturnal animals that were anything but loveable, had already solved the difficult design problems that had all but stumped the brightest engineers. It is a fascinating account, one that all can enjoy. Dawkins concludes with "I hope that the reader is as awestruck as I am, and as William Paley would have been, by these bat stories."

Numerous other examples could be cited where human designers or engineers have, perhaps unintentionally, adapted nature's designs. I can think of newsprint or writing paper that is similar in design to wasp and hornet nest material, pipes and plumbing systems that look and function much like mammalian vascular systems, solar tracking devices similar to what goes on in some flowering plants, cables and cordage designs very similar in structural design to biological fibers such as collagen, cellulose, or silk. In these cases, the design elements seem intuitive but nature has been there long before we "invented" it.

Thought Activated Prosthetics / Robotics

Can a walking stick or a crutch be considered as a biomimetic device? Perhaps, because it is intended to mimic or take the place of a leg. But if we hold to a higher standard, the earliest man made prosthetic creations discovered to date are a couple fake toes on two Egyptian mummies. The "Cairo Toe", a leather and wood contraption dating between 1069 and 664 BC is believed to have been functional because it has a joint.[16] A slightly older big toe, made from linen, glue, and plaster, was found on another mummy. But since this one lacks a movable joint, it may have been more cosmetic than functional.[17] When these two toes were discovered, they replaced a Roman prosthetic leg dating to 300 BC as the oldest known prosthetic devices. The "Roman Capua Leg" was a bronze leg housed in the Royal College of Surgeons in London until it was destroyed by German bombing during WWII.[18] A replica of the leg now resides in the British Science Museum.

Wars are particularly hard on life and limb. So it is no surprise that prosthetic development advances most during and just following major wars when the troops come home with missing arms and legs. The IEDs of the Iraq war have been especially effective in destroying limbs without killing the soldier who wear high-tech body armor. And because of advances in materials science and electronics, current prostheses have a more realistic look and feel. They are also better at performing the acts of daily living than say a wooden leg or an iron hook attached to an elbow joint. Even with the most modern artificial arm and hand, the simple task of pouring a glass of water can be a daunting task because of the fine control required. Work is underway now to design prosthetic limbs that have the look and feel of real tissue and that are wired to the thought centers of the brain to simply respond appropriately while giving sensory feedback to the brain. Current advances are truly amazing as scientists and engineers now carefully study the real thing in order to invent a fully functional facsimile.[19]

NON FADING and SELF CLEANING PAINT

We use paint to protect surfaces from environmental damage. With various types of paint we mark things for identification, for safety, giving things meaning. A new coat of paint adds color and covers up years of grime and corrosion.

Rather than applying a coat of paint however, mother nature uses a variety of ways to mark and signal. For example, following the onset of the fruit climacteric (a physiological switch that begins fruit ripening), ripening is accompanied by biochemical changes that convert acids and starches to sugars while green pigments give way to brilliant reds, yellows, blues, and purples. The bright colors invite fruit eaters to the banquet and in the process the plant benefits by having its seeds dispersed, sometimes even with a convenient dose of fertilizer. In many plants, birds, insects, fish and some molluscs, bright coloration may provide not only species recognition but also gender identification, warning, or readiness for mating etc. Many of these colors are of course due to pigments in or deposited by living cells. But some of nature's colors are structural colors.[20] That is, they are not composed of pigments at all. Pigments can fade or change chemically over time. Rather, the colors appear because of layered nanostructures that refract or diffract light from different layers leading to interference resulting in the beautiful iridescent hues. Though it is hard to believe, the dazzling peacocks, brilliant blue birds, and flashing morpho butterflies are actually brown or dirty white. Their color comes from light refracting structure rather than from pigments. Their resulting colors are not only brilliant but are also non-fading.

Current biomimetic research is rapidly developing paints that not only derive their color from the paint's ultrastructure, but these new paints are also self cleaning in that they exhibit the lotus effect.[21] (Figure 2)

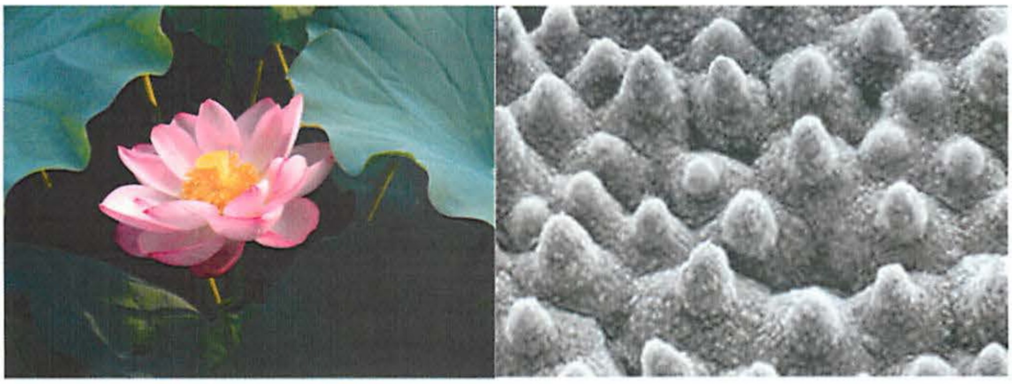

Figure 2 Left: Photo of a Lotus plant in flower. Right: Scanning electron micrograph of the lotus leaf showing the ultra tiny pegs that contribute to the super hydrophobicity exhibited by this plant. Photos from Wikimedia and http://www.nanoport.net/19,0,das-natuerliche-vorbild,index,0.html

The leaves of the lotus plant stay pristine and clean despite the fact that these tropical plants grow in muddy wetlands where they are frequently splashed by muddy water. Again, nano structure is the secret. Lotus leaves have very small cellular "pegs" giving the surface a micro-roughness. Add to that roughness the wax crystals and hydrophobic chemicals on the surface of the leaf and this adds up to a super hydrophobic surface that allows water to roll off with its load of dust, dirt and mud. No wonder paint companies are experimenting with these self cleaning and non-pigment based paints.

ULTRA SMALL and ULTRA EFFICIENT Motors

Many biomimetics projects are works in progress. They are still dreams in the minds of inventors. Ultra small biological protein motors that operate with very high efficiency have been carefully studied because they hold promise for many potential applications. For the last two decades there have been extensive collaborations between the Protonic NanoMachine Project in Japan, The Department of Biophysics at Boston University School of Medicine, the Department of Cell Biology at Harvard Medical School, the Rosenstiel Basic Medical Sciences Research Center of Brandeis University, the Advanced Technology Research Laboratories of Matsushita Electric Industrial Co., and the Department of Physics at the University of Veszprem in Hungary. As a result we now know much more about the rotary motor of the bacterial flagella and the rotary motor of the F1-F0 ATPase molecule among others.[22]

Biomolecular Nanomachines. The discovery of the rotary helical flagella in bacteria in 1974 stunned the global scientific community but its molecular structure was not worked out until just recently. With from a few to many hundreds of flagella all working together in concert, the bacterial flagella is only 20 nm in diameter and over 20,000 nm long. The bacterial flagellum consists of over 30 different proteins that self assemble following translation and folding of the resulting proteins. The proteins self assemble (no heat, beat, and treat going on here) into a tiny rotor, stator, switching unit, bushing, universal joint, and helical screw propeller which rotates at up to 20,000 RPM, can stop in 1 millisecond and be turning just as fast in the opposite direction in the next millisecond. These 10^{-16} watt motors run with greater than 80% efficiency using the energy of a proton gradient across a membrane. Building tiny efficient rotary motors could have huge practical applications. Bioengineers are not even close to being able to reproduce working facsimiles of this tiny engine yet. But they are working on it.

In 1997, John Walker and Paul Boyer were awarded the Nobel Prize for discovering the structure of the ATP Synthase engine[23]. The essentially 100% efficient rotary engine that phosphorylates ADP into ATP is even more interesting and exciting than the bacterial flagella because every living cell uses thousands if not millions of molecules of ATP to power each of its functions each and every second, 24/7. The human body actually has less than 50 g of ATP at any particular moment. That tiny amount is used and recycled three times every minute, which amounts to more than 200 kg of ATP used during each 24 hour period. The engine, which makes this all-important ATP, is called ATP synthase (also known as the F1-F0 ATPase) and has more than fourty thousand atoms precisely organized into the F1 stalk surrounded by the F0 head composed of 6 globular proteins. The base of the stalk is embedded in the mitochondrial membrane where it is made to rotate as protons are channeled through a stationery "A" protein (we don't know the structure of this protein yet). Protein chemists and bioengineers are working to determine how this system works so they can design molecular nanoengines that will work with 100% efficiency.

Other biomimicry applications include:

1. Navigation systems using the sun, stars, infrasound and the earth's magnetic field – used by birds, insects, reptiles, and mammals in their annual migrations.[24]
2. Super glues that cure quickly and bond tightly – used by barnacles and oysters.[25]

3. Hook and loop (Velcro) technology that can be used for a variety of attachment applications – used by seeds, stems, burrs as a means of seed conveyance and propagation.[26]
4. Generating cold light – used by bacteria and many phosphorescent organisms.[27]
5. Flight surfaces that generate lift – used by birds[28]
6. Antibiotics – used by fungi, plants[29]
7. Pharmaceuticals – created by assorted plants and fungi.[30]
8. Light but strong structural support – as is found in bird skeletal structures and echinoderm spines.[31]
9. Robotic guidance systems – modeled after those used by desert ants.[32]
10. Blade and wing tubercle technology (Figure 3) - used by Humpback whales [33]

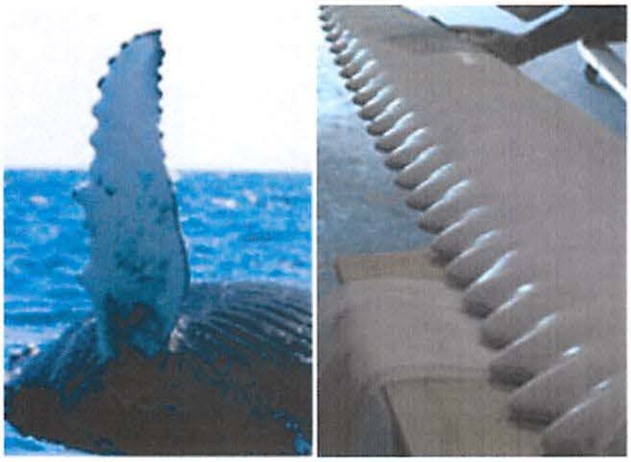

Figure 3 Humpback whale fin and fan blade from wind generator. Photo from http://www.whalepower.com/drupal/

11. Pipe/conduit structures with associated pumps and valves[34]
12. New ultrahard ceramic composits - mimic mother-of-pearl[35]
13. Crystalline polymers such as silk, collagen, cellulose, and chitin are being studied to make better and stronger man-made fibers along the lines of nylon, polyester, Kevlar, and carbon fiber products.[36]
14. New wastewater treatment protocols modeled after streamside biology[37]
15. Etc.

DISCUSSION OF PURPOSE

Are the materials, structures and systems described above plus the countless other structures found in nature the result of a purposeful mind or not? Is there a way to know for sure? What exactly is meant by "purpose" or "design"? I choose to examine the criteria for purpose or design first and then think about how we can know for sure if purpose or design is involved in biological structures.

Aristotle (384 - 322 BC) seems to have set the standard for what constitutes purpose first. He argued that the deciding factor was whether or not something was planned in advance. Of his four causes, Aristotle's final cause was equivalent to the goal or the purpose of the thing. He strongly believed in purpose. But because a cause suggests a first cause i.e. God, and because a purpose smacks of anthropomorphism, most biologists are quick to point out that biological systems do not have purpose.

Forcefully articulating the views of many mainstream biologists, Francis Crick states, "Biologists must constantly keep in mind that what they see was not designed, but rather evolved."[38] Dawkins echoes with, "Natural selection is the blind watchmaker, blind because it does not see ahead, does not plan consequences, has no purpose in view."[39]

I find it very interesting that in spite of the consistent message of a purposeless naturalistic evolution that is taught in public schools and is proclaimed in the popular press including all types of media, the general public in the United States remains unconvinced. That GOD was indeed involved in the creation is the opinion of more than 80% of those polled over the course of the last 22 years.[40] Though the individuals polled were not asked why they believed what they did, my conjecture is that a preponderance of believers probably believe in creation because it is hard to doubt the senses. The public is generally aware of the complexity of living systems. Even though the proverbial "man-on-the-street" can not describe the cell very well or name many of its parts, he understands that the cell is a highly complex entity. People realize that, in many of its parameters, the universe appears tuned for the existence of life. They just can't make themselves believe that all this happened by chance. Thus when asked, they invoke a designer or a first cause to explain what they instinctively feel. The purposefulness of biological systems is a "gut feeling". Even professional biologists who reject the concept as out of hand keep returning to wrestle with the nagging feelings[41].

Dembski's Criteria

Apart from inspiration, this instinctual or gut feeling about what constitutes design is all that we have had to go on. All we had, that is, until William Dembski. Arguably the best analysis providing rational quantitative design guidelines was recently proposed by William Dembski, first in his book *The Design Inference*[42] and then popularized in *Intelligent Design*[43]. Dembski suggests three criteria that must be met in order for one to be able to say with a standardized level of certainty whether or not design or purpose is involved when thinking of a situation.

His reasoning, which I like very much, depends on the answers to three questions.

All three questions must be answered in the affirmative in order to qualify as purposeful or designed.

1. Is the thing or process in question dependent on choice? i.e. if the process or thing will happen automatically based on natural laws and there is no other way that it can happen, then there is no choice. But if there are multiple outcomes or alternatives that could happen, then choice is involved and the answer to this question is "YES".
2. Is the thing or process in question complex? Dembski's measure of complexity has to do with its probability. i.e. Is the probability less than 1 chance in 10^{150} of making the thing or having the process in question happen? Note that this is an extremely small arbitrary probability set by Dembski. The probability of making certain molecules or having an event happen can usually be calculated. If the probability is less than 10^{-150}, then the answer to his complexity question is "YES".
3. Is the thing or process in question specified? i.e. does the thing or process in question fit a known specific pattern? If the thing or process doesn't fit a known pattern or we have to create the pattern after the fact, then we must answer "NO" to this question. But if the thing or process is a very specific patterned construct or process then we should answer "YES" here as well.

Note that one must answer "Yes" to all three questions in order for the thing or process to meet Dembski's criteria for calling it planned or designed.

Assuming that we can answer Dembski's questions and determine probabilities, then we can apply his standard to cellular structures or molecules or metabolic pathways or processes and determine if they are designed or not. Are Dembski's rules too relaxed or too stringent? My sense is that he has drawn the lines quite conservatively–i.e. highly stringent. Yet, despite this high standard, most biological systems easily qualify as designed systems.

For me, Dembski's criteria provide a convenient way to quantify and make consistent decisions for most structural elements. But will Dembski's criteria identify every purposeful design? Perhaps not. For example, a bump on a log may appear useless and purposeless. But when an intelligent mind uses the bump in some meaningful way, perhaps even shaping the bump into a cam on a shaft, a barb on an arrow, or a cog on a wheel, the bump takes on crucial importance. I would argue that it is the mind of the inventor/designer that gives a structure purpose. If pressed, I could perhaps envision a simple designed structure or system that might not garner three "YES" answers using Demski's criteria.

The Test of Scripture

But biological structures and systems are anything but simple. Using Dembski's test most would easily qualify as designed. For the sake of argument however let's imagine that a simple biological structure didn't pass Dembski's test, is there an alternative test that can determine whether or not it was designed? For me the answer is yes and that test is the test of scripture.

God's word is very clear in answering the question of purpose, of God as creator, and of God as an intelligent master designer. Yet it is true that for those who do not accept either Dembski's criteria for design or the existence of God, they naturally exclude God's inventive mind from the equation. This explains why one who does not believe in God might look at an exquisitely complex biological structure and see nothing more than a chance arrangement of matter that just happens to be useful for a particular function. To illustrate this point, a hammerless camper might use a convenient rock to pound a tent stake into the ground. The rock happens to be there and happens to be the right size and heft to be used as a hammer. But just because it can be used as a hammer, the biologists would argue that it could be used for many other purposes as well. Besides a hammer it could be used as a wheel chock, a boundary marker, a weapon to fend off a thieving raccoon or any other number of purposes. So a structure function relationship does not in itself endow purpose. Rather, it is the mind of the intelligent camper that gives the rock purpose. At this point, I must agree that, without God and his intelligent mind, this is a purposeless universe indeed.

When I choose to accept the reality of God and the veracity of His word, suddenly the universe is filled with purpose. From "The Beginning" to "The End" the Bible brims with statements of purpose and meaning. When I read those statements as statements of fact, structures from the galactic scale to the nano scale have all the appearance of having been invented, designed, and meticulously crafted by skillful fingers (or voice) by the command of a purposeful mind.[44] I find deep personal satisfaction and a comfortable philosophical fit between my *a priori* belief in the Creator God and the swelling flood of biomimetic data giving evidence of even more exciting structure/function relationships.

APPLICATION TO TEACHING

The careful study of biomimetic applications, the in-depth search for new engineering solutions, the detailed analysis of biological structure and function in a quest to design bionic systems, these are all wonderful ways to involve students in learning biology. It gives me, the biology teacher, an up to date and very practical approach for enhancing student learning. The pedagogical advantages are obvious.

The added value of biomimetics, I believe, is its in-your-face presentation of structure function relationships. The search for purposeful solutions often bring me and my students to a point of interacting with the purposeful Creator who made what we are studying. These are opportunities to invite my students and research colleagues to think about these exquisitely designed structures and to think about the joy that is ours when we fulfill God's purpose for our lives.

WHAT THE BIBLE SAYS ABOUT PURPOSEFUL DESIGN

Consider some of the inspired Biblical testimony and put it into the context of all these very specifically designed biosystems that are being copied and adapted. The

Creator asks "Hath not my hand made all these things?"[45] The psalmist states, "How great are your works, O LORD, how profound your thoughts!"[46] or "How precious to me are your thoughts, O God! How vast is the sum of them! Were I to count them, they would outnumber the grains of sand."[47] My favorite passage is Isaiah 40:28 which reads, "Have you not known? Have you not heard? The everlasting God, the LORD, The Creator of the ends of the earth, neither faints nor is weary. His understanding is unsearchable." Clearly God knows so much more than we do which led Paul to exclaim, "Oh, the depth of the riches both of the wisdom and knowledge of God! How unsearchable are His judgments and His ways past finding out!"[48]

Truly God is the master inventor–the master creator and designer. His thoughts are not our thoughts. Who can know them? I choose to believe the Word of God where it says in John 1:1-3. *In the beginning was the Word, and the Word was with God, and the Word was God. He was with God in the beginning. Through him all things were made;* ***without him nothing was made that has been made.***

And the word is very explicit about God being a purposeful God. The account of creation resounds with the repeating theme that "It was good" and that "It was very good". That it "was good" suggests that, somewhere in the vaults of heaven there was a master plan. There were design standards and specifications for each particular structure or collection of structures. That the results were good suggests that when the finished creation was compared to the divine specifications, the match was a good match. God could look over his work at the end of each day and pronounce it to be "good".

To be sure, the created works have changed significantly since the "it-was-good" creation. Perhaps most of the changes that we see result from loss of original function. Many changes and adaptations are clear evidence of a creative genius that knew how to design systems that readily adapt and thrive under very different and ever-changing environmental conditions. Yet another category of biological change is problematic and appears to be the result of a malevolent mind and hand. Taken together, changes like these may obscure the evidence of purpose.

None-the-less, the Bible is filled with assurances of God's purpose in the creation, for us and our lives, and even for national events. Near the end of creation week, the pronouncement from God is that "every seed-bearing plant on the face of the whole earth and every tree that has fruit with seed in it . . . will be yours for food". The plants were put here to feed us as well as "all the beasts of the earth and all the birds of the air and all the creatures that move on the ground – everything that has the breath of life in it". That is a marvelous statement of purpose. God's explicit stated purpose for plants is for food. God didn't create us and then leave us to fend for ourselves. Every detail of the creation made provision to care for every human need.

Just after describing the spoken-into-being creation, the psalmist David describes how the Lord intervenes in the history of nations, "The LORD foils the plans of the nations; he thwarts the purposes of the peoples. But the plans of the LORD stand firm forever, the purposes of his heart through all generations" (Psalm 33:10-11) God is indeed a purposeful God. He is not a capricious or careless God. What's more, his plans are firm and do not change.

Throughout the process of writing this essay, I have been impressed again and again how even the ungodly marvel at the wealth of purpose evident in natural systems. Though they use different words than I would choose, they gush on an on about the beauty and utility of these evolved systems. Furthermore, they dedicate their lives to discovering and adapting the systems and structures for human use through their "new inventions".

In summary, we have seen that biomimetics is a field of study that is actively searching through the vast array of nature's design elements looking for those that might make useful "inventions". More than that, we have learned that biomimetic scientists are particularly eager to change manufacturing processes to make them more environmentally friendly. We have looked at just a few of the thousands of biomimetic projects either successfully concluded or still under way. And we have wrestled with the meaning of purpose and how one is to decide whether purpose or design is involved in any particular structure or process. But most important, in looking at a few examples of biomimicry, we have seen the unmistakable fingerprints of an extravagant creator GOD who has a purpose for each design element in each of these elegant systems. And in understanding His purposefulness in each and every element of His vast creation, we can be assured that he has a purpose for us too.

"For I know the plans I have for you," declares the LORD, "plans to prosper you and not to harm you, plans to give you hope and a future." Jeremiah 29.11

End Notes

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[1] All of the texts in this section are from the New International Version, Copyright 1984 by International Bible Society. "But the plans of the LORD stand firm forever, the purposes of his heart through all generations." Psalm 33:11, "Many are the plans in a man's heart, but it is the LORD's purpose that prevails." Proverbs 19:21, "For the LORD Almighty has purposed, and who can thwart him? His hand is stretched out, and who can turn it back?" Isaiah 14:27, "Through him all things were made; without him nothing was made that has been made" John 1:3

[2] A recent news story appeared in the National Geographic under the title: Biomimetics: Design by Nature by Tom Mueller. National Geographic Magazine. April, 2008. The online edition of that issue is found here: http://ngm.nationalgeographic.com/2008/04/biomimetics/tom-mueller-text and then there are numerous news stories like this one from Mother Nature's Design Workshop: http://www.businessweek.com/technology/content/jun2006/tc20060627_504809.htm?chan=search by Carlos Bergfeld, News Analyst for Business Week, June 27, 2006

[3] There is a large body of literature on purpose in biological systems. Whitehead sums it up nicely. "Many a scientist has patiently designed experiments for the purpose of substantiating his belief that animal operations are motivated by no purposes. He has perhaps spent his spare time in writing articles to prove that human beings are as other animals so that "purpose" is a category irrelevant for the explanation of their bodily activities, his own activities included. Scientists animated by the purpose of proving that they are purposeless constitute an interesting subject for study." Whitehead, A.N. 1929, The Function of Reason. (Princeton University Press). See also Monod, J. 1970. Chance and Necessity: An Essay in the Natural Philosophy of Modern Biology. (London. Collins).; Dawkins, Richard. 1986. The Blind Watchmaker. (New York. WWNorton & Company Inc).; Agutter, Paul S. and Denys N. Wheatley. 1999. Foundations of Biology: On the problem of "Purpose" in biology in relation to our acceptance of the Darwinian theory of Natural Selection. Foundations of Science 4:3-23; Rignano, Eugenio. 1931. The Concept of Purpose in Biology. Mind, New Series. 40(159):335-340; and Crick, Francis. 1988. What Mad Pursuit (New York; Basic Books), p. 138.
[4] Bar-Cohen, Joseph (ed). 2006. Biomimetics: Biologically Inspired Technologies. (Taylor & Francis, New York). 527 pages. This CRC publication, edited by one of the leaders in biomimetics, contains a catalog of inspiring examples of how biomimetics inventions are being used in a wide variety of applications. Further, it describes the challenges and potential for future work. Another informative source is Wainwright, S.A., W.D.Biggs, J.D.Currey, and J.M. Gosline. 1982. Mechanical Design in Organisms. Princeton University Press, Princeton, New Jersey. This technology is so new that a journal was introduced in 2006 called Bioinspiration and Biomimetics. And here is a web page http://www.iop.org/EJ/journal/1748-3190 describing this journal from the Institute of Physics (IOP).
[5] Otto H. Schmitt first used the word biomimetics in 1969. Schmitt, O.H., Some interesting and useful biomimetic transforms. Proceedings of Third International Biophysics Congress, Boston, Massachusetts, August 29-September 3. p. 297.
[6] Vincent, J.F.V. "Stealing ideas from nature". S. Pelligrino (Ed.) Chapter 3 in Deployable Structures. Springer-Verlag, Vienna. pages 51-58.
[7] http://www.velcro.com
[8] http://rst.gsfc.nasa.gov/Sect8/Sect8_2.html is an informative piece on how radar works. And then this web page http://www.bathouseproject.org/resource/articles/echolocation/ is a reprint of Chapter 2 from Dawkins, Richard. 1986. The Blind Watchmaker. WWNorton & Company, New York 332 pages.
[9] http://www.flyingmachines.org/davi.html and Usher, Abbott Payson. 1988. A History of Mechanical Inventions. see especially Chapter 9, Leonardo da Vinci: Engineer and Inventor. Courier Dover Publications. 450 pages.
[10] Sever, M.J., J.T. Weisser, J. Monahan, S Srinivasan, and J.J. Wilker. 2004. Metal-Mediated Cross-Linking in the Generation of a Marine Mussel Adhesive. Angewandte Chemie International Edition, 2004, 43:447-450.
[11] Janine Benyus made this reference to "Heat, Beat, and Treat" in an wonderful talk to a TED audience entitled "12 sustainable design ideas". The engaging presentation can be downloaded here: http://www.ted.com/index.php/talks/janine_benyus_shares_nature_s_designs.html
[12] http://cnx.org/content/m14503/latest/ and http://www.infoweblinks.com/content/integratedcircuits.htm and http://www.pccomputernotes.com/integrated_circuits/ics.htm
[13] One very interesting research paper describing the ongoing work is: Prescribing diatom morphology: toward genetic engineering of biological nanomaterials by Nils Kroger in Current Opinion in Chemical Biology. 2007. 11:662-669. (Elsevier)
[14] Benyus, Janine M. 2002. Biomimicry: Innovation Inspired by Nature. Harper Perennial. 320 pages.
[15] Dawkins, Richard. 1986. The Blind Watchmaker. WWNorton & Company, New York 332 pages.
[16] http://www.livescience.com/history/070727_old_toe.html
[17] http://news.bbc.co.uk/1/hi/health/6918687.stm
[18] http://www.sciencemuseum.org.uk/objects/classical_and_medieval_medicine/A646752.aspx and more found here: http://en.wikipedia.org/wiki/Roman_Capua_Leg
[19] a popular and easy to read account is found in this article The dawn of the bionic man. The Week. June 13, 2008. 8:11; see also Autumn, Kellar, Metin Sitti, Yiching A. Liang, Anne M. Peattie, Wendy R. Hansen, Simon Sponberg, Thomas W. Kenny, Ronald Fearing, Jacom N. Israelachvili, and Robert J. Full.

2002. PNAS Online. 99(19):12252-12256 and online here: http://www.pnas.org/cgi/content/long/99/19/12252

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[23] http://nobelprize.org/nobel_prizes/chemistry/laureates/1997/

[24] http://animals.howstuffworks.com/animal-facts/animal-migration.htm/printable

[25] Hight, L.M. and J.J. Wilker. 2007. Synergistic effects of metals and oxidants in the curing of marine mussel adhesive. J Mater Sci. 42:8934-8942 Here they report that both iron and hydrogen peroxide together provide synergistic curing which cross-linked the mussel adhesive proteins better than either one alone.

[26] http://www.velcro.com, and http://en.wikipedia.org/wiki/Velcro

[27] Deo, S.K., M Mirasoli and S. Daunert. 2005. Bioluminescence resonance energy transfer from aequorin to a fluorophore: an artificial jellyfish for applications in multianalyte detection. Analytical and Bioanalytical Chemistry, 381: 1387-1394.

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[37] http://www.treehugger.com/files/2005/04/biomimetics_inv_1.php A web source describing how wastewater can be processed using methods like those used along stream banks. More is available at the Biolytix.com website too.

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