Running Head: BIOMIMICRY IN ENVIRONMENTAL SCIENCE

INSTRUCTION

The Integration of Biomimicry as a Solution-Oriented Approach to the Environmental Science Curriculum for High School Students.

Hilary Staples

In Partial

Department of Education: Dominican University of California

2005

ACKNOWLEDGEMENTS

I would like to thank my faculty advisor and a force in the Division of Education at Dominican University, Madalienne Peters as well as Linda Sartor for her many edits of early drafts. I also received crucial help from fellow masters students Anne Meyer and Susan Tynes, in the editing stages. Jeremy Eddy, who works closely with the Biomimicry Guild, was also an energetic and analytical companion and who helped me to design and try out curriculum ideas in the classroom. And of course, I would like to thank my brother, Judd Staples and my aunt Donna Staples for helping edit and giving an outside reader's advice.

TABLE OF CONTENTS

ABSTRACT

Biomimicry is an interdisciplinary science in which scientists look for solutions to human needs in nature. It endeavors to discover answers from the molecular, or material level, all the way up to the interrelationships, or systems level. The purpose of this review of the literature is to demonstrate the need and potential application of this new science in high school environmental science curriculum. Historically students of Environmental Science have been beleaguered by the overwhelming statistics of human failings and environmental destruction. However students need an opportunity for true hope. Biomimicry begins by inspiring admiration for the remarkable adaptations that organisms historically deemed ‘lower’ or ‘primitive’ employ, and facilitates the humility to recognize there is much to learn from them. In addition biomimicry provides scientific solutions that can be partnered with economic, environmental, and even spiritual growth. It encourages a perspective shift by transferring energies to creativity and ingenuity, revealing solutions and sustainability.

INTRODUCTION

Often the take home message for students in environmental science classes is that humans are the problem in the decline of environmental health. Students can be left feeling overwhelmed and hopeless in the face of these complicated issues. Learning about positive solutions and ways to take meaningful action are powerful ways to rejuvenate optimism. The integration of the concepts of biomimicry can accomplish these two goals (learning about the problem and finding solutions for action) simultaneously.

This paper approaches this subject on two levels. In the first part background information about the state of environmental education and the need for improvement in ecological literacy are formulated. The second part of the paper is to be used as a resource for educators. In this section a four defining examples of biomimicry are specifically explored Followed by a comprehensive listing of examples in Appendix A. In addition curriculum suggestions are shared as well as additional resources listed in Appendix B.

PURPOSE

The purpose of the review of the literature is to introduce the reader to the concept of biomimicry and to explore the multiple levels and the scope of this perceptual shift in thinking about solution to human needs and environmental issues. In addition, the need for the inclusion of biomimicry in environmental science curriculum is demonstrated.

REVIEW OF THE LITERATURE

Often the take home message for students in environmental science classes is that humans are the problem in the decline of environmental health. Students can be left feeling overwhelmed and hopeless in the face of these complicated issues. Learning about positive solutions and ways to take meaningful action are powerful ways to rejuvenate optimism. The integration of the concepts of biomimicry can accomplish these two goals simultaneously.

Biomimicry is not a familiar term to many. Therefore, the review of the literature begins with the definition of biomimicry. There has not been formal integration of this concept into education or environmental science curriculum. I explore the science of biomimicry and tie it to current research on environmental education as an integrating concept in order to demonstrate the potential fit of biomimicry in high school curriculum.

In reviewing the current state of environmental education, its positive learning outcomes and the support for environmental-based learning in our schools are revealed. However, due to the overwhelming scientific evidence demonstrating a seemingly hopeless state of the environment, a constructive solution-based curriculum in environmental science is important. Biomimicry is the suggested guiding principal for what I consider to be a paradigm shift to creative and problem-based learning necessary for education toward sustainability. Resonant with the words of a leading scholar of biomimicry Janine Benyus (2004), “I know all of the statistics of destruction, but I’ve chosen to come to this out of love, because I love this place. And I want to stay here. I want to stay home” (p5).

Biomimicry Defined

> **Biomimicry** (also **biomimickry**) is the conscious copying of examples and mechanisms from natural organisms and ecologies. It is a form of applied case-based reasoning, treating nature itself as a database of solutions that already work. Proponents argue that all natural life forms minimize and ecological niches remove failures. (http://en.wikipedia.org/wiki/Biomimicry, 2005)

In nature, there are many examples of *mimicry* in which one species imitates the good design of another in order to benefit within the environment. A famous example is the Viceroy butterfly, which although a tasty and relatively harmless prey, mimics the flashy orange and black warning coloration of the toxic and bitter tasting Monarch butterfly, thereby avoiding being eaten. The military has long looked to nature to inspire camouflage strategies (Forbes, 2003), protective gear (Bragdon, 2005), sonar technology, and more recently surveillance and reconnaissance robots (Stone 1999). Scientists engaged in the study of biomimicry, sometimes known as biomimetics, are also looking to nature to find solutions for stronger more durable materials, adhesives, and medicinal cures. They are working on everything from canes inspired by bat sonar to aid the blind to the new shark skin inspired Speedo™ swim suit (Harvey, 2004). Think tanks such as the Rocky Mountain Institute are using the biomimicry paradigm to take on manufacturing that addresses some of architecture’s greatest challenges: color, adhesion, dehumidification, materials, protection, responsiveness, and more (Baumeister, 2004; Hawkin, 1994; Hawkin, Lovins, & Lovins, 2002).

This is an exciting time for the study of *Biomimetic*, *Bionics*, or described here as *Biomimicry*. Our technology is finally advanced enough that we are able to probe to the molecular and mechanistic levels of biology while our engineering library is growing in its fabrication techniques and abilities (Collyer, 2001; Dickinson, 1999). The ingenious designs of nature go beyond time-tested feats of engineering. Nature creates its products in ways that do not require the "heat, beat, and treat" methods of human industry (Benyus, 2002). In addition, it is all accomplished with resources available locally and without the creation of problematic waste. "Biomimicry is a new way of viewing and valuing nature. It introduces an era based not on what we can extract from the natural world, but on what we can learn from it" (Benyus, 2002, introduction). When we "look to nature as a teacher" as Janine Benyus has suggested, we have an entirely new lens in which to look for solutions (2002). These *bio-pioneers*, or *bioneers*, can be farmers who are looking to nature for answers to soil fertility (The Land Institute); water treatment centers for help in filtration (Ausubel, K., 1997; 2005; Lerner, S., 1997); and economists looking for models in sustainable business practices (Hawken, et al., 2000; Lerner, S., 1997).

"Doing it nature's way has the potential to change the way we grow food, make materials, harness energy, heal ourselves, store information, and conduct business. In each case, nature would be model, measure, and mentor" (Benyus, Biomimicry Explained, FAQs 9). Einstein wisely stated "[t]he significant problems we face cannot be solved by the same level of thinking that created them" (as quoted in Benyus, 2002, p. 247). It is time to both acknowledge the difficult issues that face the integrity of ecosystem health as we know it and venture whole-heartedly to find solutions. True adoption of a biomimicry based view of business and industry takes innovative and interdisciplinary teams. No longer can economists or material chemists do without the input of biologists and ecologists. Providing for our needs by sustainable means involves new ways of integrating ideas, pioneering research, and problem-solving in ways that involve dropping assumptions and being humble before 38 million years of evolutionary design. This big thinking is why Janine Benyus was awarded Cultural Thinker of 2002 by Sputnik, and has been asked to speak at colleges, conferences, and companies around the world. She has been asked to sit in on meetings with major designers such as Nike and Interface, Inc. (Buckminster Fuller Institute, 2001), biologists, and even government dignitaries, such as Prince Charles in January (Bragdon, C., 2005).

As Janine Benyus (2002) sees it, there are 10 simple lessons we can learn from nature and apply to business, agriculture, science and our lives. Organisms in mature ecosystems:

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 (pp. 254-5)

Secondary education is an arena ripe for introducing this fresh way of looking at our problems and engaging in a solution-oriented interdisciplinary curriculum. Environmental science curriculum already explores the human systems and their implications on the environment in which we are nested. According to David Haury (1998; 202) and The National Forum on Partnerships Supporting Environmental Education(1996) environmental issues traverse geo-political boundaries and traditional discipline boundaries; they encompass the life sciences (biology, earth sciences), social studies (economics, anthropology, geography, and history), and the humanities (philosophy, the arts, ethics and literature). It is my belief that biomimicry, with its roots in integrated systems functioning, can serve as a guiding concept to aid students in thinking about solutions to the problems that cross over these traditional boundaries.

The State of Environmental Education

Biomimicry has implications for incorporation in many different disciplines. The most accessible area of integration would be in an environmental science course or an educational program with uses environmental education as a fulcrum or foundation. For the purpose of this paper I will define environmental education (EE) as it is specified by the National Environmental Education and Training Foundation (2002):

> educational efforts that increase public awareness and knowledge about environmental issues while providing critical thinking, problem-solving, and effective decision-making skills. The main goal of EE is for people of all ages to know enough about environmental science and related social issues to make sound and well-reasoned environmental decisions.

Inherent in the application of biomimicry in the curriculum is acceptance of environmental education as an integral part of an educational program. The American public shows support for environmental education in the school system. In addition, many scientists acknowledge the importance of ecological principals being taught in order to prepare the next generation for lifestyle and governmental decisions. However, one finds educational systems are not universally integrating these concepts into schools.

Public Opinion of EE

A 1992 opinion poll by the Columbia Broadcasting System (CBS) reported that 2/3 of Americans polled believed that "environmental problems are so important that solutions must be found regardless of cost" (Zimmerman, 1996, Abstract). The National Environmental Education & Training Foundation (NEETF) has commissioned Roper Starch Worldwide to conduct a survey of adult Americans (representative sample of 1,505 Americans, age 18 and older) about their views on the environment and education annually since 1992. Over the past few years, Americans seemed to have settled into a consistent result pattern. The most recent report (2001) shows that Americans say that a balance between the environment and the economy is required for prosperity. Fully 89% either strongly or mostly agree that "the condition of the environment will play an increasingly important role in the nation's economic future" (p. 2). Thus, Americans believe that environmental protection and economic development must be achieved together to ensure a vibrant nation. When people are asked to choose between environmental protection and economic development, 71% say they would choose the environment. However, everyday actions by adults in support of the environment are showing a slight fall-off, and environmental "illiteracy" remains widespread (p.3).

There seems to be a major discrepancy between what Americans believe and desire, and what is currently practiced by industries and academia. In 1999 only 100 of 700+ business management schools even offered courses on the interface of business and the environment, let alone required them. Medical students train an average of 6 hours of environmental medicine in their 4 years of training. And although environmental education is becoming an increasing part of state standards, less than 10% of teachers'/credentialing colleges require a course in environmental education to teach at the elementary or secondary level (Bogo, 1999). And even as states incorporate environmental education into their standards the majority of schools have not received adequate curriculum materials or training (Benetti, 2002; Poore, 1993).

Education about the environment is essential, and needs to become a more central principal of our schools. In order to be better stewards of the environment, the primary step is to ensure the information is available (Gang, 2004). The NEETF survey found 95% of those adult Americans (including 95% of parents) believe that environmental education should be taught in our K-12 schools (p1). The World Commission of Environmental Development (1987) specifically states that teacher training is crucial for the development of a sustainable society (Ekbourg, 2003). Indeed, educators who are teaching about global issues, from the environment to human rights, are "very much on the cultural frontline" in their job to interpret the state of the world to their students" (Steiner as quoted in Hicks, 1998). Well-balanced and problem-based curricula are essential resources for our teachers.

Ecoliteracy

Supplying students with this foundation of environmental knowledge is now being referred to as *ecoliteracy* (Center for Ecoliteracy). "Environmentally literate students and adults should be able to use and apply the basic ecological concepts when considering environmental problems or issues" (Munsen, 1994, p. 1). Biomimicry stands out as a means for insuring the goals that Americans seem to hold. It augments science education as well as environmental education, while at the same time fostering concepts necessary for sustainable economics.

Sustainability means living as part of the web of life; and therefore, building communities in which we can satisfy our needs and hopes without diminishing the chances of future generations of humans and other species. Natural systems theorists, Fritjof Capra writes about ecoliteracy and sustainability:

> For this task we can learn valuable lessons from the study of ecosystems, which *are* sustainable communities of plants, animals and microorganisms. To understand these lessons, we need to learn the basic principles of ecology. We need to become, as it were ecologically literate. Becoming ecologically literate, or *ecoliterate*, means understanding the principles of organization of ecological communities (ecosystems), and using those principles for creating sustainable communities. (1996, p. 297)

If we compare present western human behavior to biological systems, we have been acting like what ecologists refer to as a Type I species. These are the pioneer species that move in rapidly after a disturbance and take over an area. Imagine the wildflowers, grasses, and weeds that rapidly spring up after a forest fire. Their strategy is opportunity and stealth. They take more resources than they return because they are not invested in the long term health of the ecosystem. However in time, like the hare and the tortoise, slower growing species which take the time to nurture soil and put down roots begin to shade out the type I species. Eventually you have a climax community, like an old growth forest. These communities must necessarily commit to investing in the future because they cannot move on, and therefore depend on interrelationships to keep energy and matter exchanging.

There is nothing inherently wrong with the Type I strategy, so long as there is a new open patch of land for the species to take over (Benyus, 2002). There was a time when there seemed to be a limitless supply of land, water and resources for human exploitation. However, now we know that our resources are finite and that there are more humans than ever before. It is time for a shift of strategies. It is time for us to start acting like we are part of a mature ecosystem. Therefore, we need to stop clinging to the pioneer strategy that we employed (and of which Americans were even proud) for so long.

The teaching of interconnectedness is a critical aspect of education for a sustainable future. These interconnections lie in the underpinnings of the universe, elucidated by quantum physics. In this science, mathematics is used to describe the behavior of subatomic particles. We find that matter, of which we are all made up, is not a bunch of things, but a series of relationships (Capra, 1996). On a larger scale we see this in the balancing dynamic of symbiotic and predator prey relationships that construct ecosystems. “These, then, are some of the basic principles of ecology-- interdependence, recycling, partnership, flexibility, diversity, and as a consequence of all those, sustainability” (Capra, 1996, p. 304).

The Roper Starch survey (2001), in addition to surveying American opinions about environmental education, also included a basic knowledge quiz. The results of this quiz indicate that “Americans lack the basic knowledge and are unprepared to respond to the major environmental challenges we face in the 21st century” (NEETF, 2001, p. 1). And yet we see that the need is great. The need is also being recognized by world leaders as they have begun meeting in earnest to discuss the importance of sustainability at global conferences. The Earth Summit at

Rio de Janeiro in 1992 and in Johannesburg in 2002, the Montreal Protocol, and the Kyoto Protocol of 1998, all demonstrate that environmental problems are being acknowledged by governments from around the world. To accomplish this task we can learn valuable lessons from the study of ecosystems, which are sustainable communities of plants, animals, and microorganisms (Capra, 1996; Orr, 1992).

With many environmental issues becoming more complex and pervasive, we are no longer able to depend solely on a few experts. A stronger public understanding of environmental science is a growing necessity (Coyle, 2004; Tapia & Blochman Eds., 2000). It is important that we are supplying our students with scientific foundations to compensate for the media barrage of misinformation and misconceptions that they must sort through every day (Hewson & Hewson, 1998). Indeed, as Aldo Leopold, the father of ecology, stated "[b]iological education is a means of building citizens" (1986, p. 208).

Ultimately how and what we teach our students has the potential to affect both attitude and knowledge base. This combination of motivation and information informs daily decisions, business choices and political interests (Heimlech, 1992). Environmental education goes beyond just learning environmental science information, it also fosters the kinds of basic life skills that are cited as necessary for success in the future. Liebermann and Hoody (1998) found that, using education about the environment as an integrating context for learning, students gain additional educational benefits, including: "a comprehensive understanding of the world; advanced thinking skills leading to discovery and real-world problem solving; and, awareness and appreciation of the diversity of viewpoints within a democratic society" (p. 2).

In addition to the knowledge base that environmental education aims to achieve, it also has a positive influence on learning in general (Glenn & Sward, 2000; NEETF, 2002). Schools using environmental interdisciplinary programs are showing considerable improvements in other learning outcomes as well. In a comparison of 40 schools in 12 states Lieberman and Hoody (1998) found the overall patterns of: improved standardized testing scores, reduction of discipline problems and improved attendance, increased orientation toward service, increased parent involvement, and increased teacher participation in professional development. Indeed integrating disciplines and the use of environmental themes for problem based learning accomplished more than just the infusion of knowledge but also changes in attitude (Heimlich, 1992). Similarly, the NEETF, chartered by congress, found similar findings in a case study report of five schools in five states who adopted environmental programs as an integrating point in academic programs. (NEETF, 2000). Biomimicry, by virtue of its environmental backbone can be a part of the continuing augmentation of environmental curriculum in schools.

Environmental science is about making connections. Connections are expressed with in the interrelationships in natural systems but also disintegrate the human-made divisions between school disciplines. Integrated learning, which centers on problem-solving, teaches creativity and decision-making skills that apply to real world problems rather than abstract ones (Disinger, 1992; Glenn & Sward, 2000; NEETF, 2002). Liebermann and Hoody (1998) found that students in these types of environmental based learning programs were better able to transfer what they learned in science to “to interdisciplinary tasks at school, at home and in their communities” (p. 6).

By looking at environmental issues which are part of our everyday lives students are able to learn that they can be the problem solvers and the change agents in the world. Biomimicry is an explicit way of using ecoliteracy to address real- world problems and elucidate that solutions and hope is obtainable.

Biomimicry Providing Hope in Environmental Science

"The most influential lesson I retained from the Biomimicry and Architecture course was to 're-learn' how to study with all my senses the wonderful complexity of my surroundings again, especially the natural world" (Neumann, 2004.) Biomimicry can serve as a fulcrum for learning issues about the environment. Indeed it is just the unifying theme that is needed in environmental education. Biomimicry provides an example that can serve as a model, a conceptual framework that permits and enhances the exploration of our world. Instead of having to do cost benefit analysis of human health and the environment and working to clean up our mess we could instead model our systems after nature and potentially avoid the waste from the beginning.

The integration of biomimicry into environmental curriculum stands a promising new teaching paradigm for two main reasons. First, there is a need for the transference of optimism and hope in the dialog of environmental issues. Second, it is one way to address the critical importance of education for a sustainable future.

In 1997 David Sobel coined the term "*ecophobia*." In his paper he critiqued the practice of teaching environmental problems to children too young and thereby leaving them with a feeling of disempowerment (Sobel, 1995; 1997). Subsequently, this concept swept through the environmental education community. Certainly, it is best to first teach a love and appreciation for nature and only later increase the information and complexity. In California, our state standards follow this construct. Environmental issues are not introduced until the high school years. However, even older students can feel overwhelmed by all of the “doom and gloom” that many of the statistics reveal.

There is a growing branch of psychology often referred to as *ecopsychology* which addresses some of these very issues. Although it is beyond the scope of this paper to delve deeply into this school of thought it can be defined to give perspective. *Ecopsychology* looks to expand the framework of psychiatric thought to include the natural environment. In other words, behavior leading to destruction of the natural world can have similar psychiatric effect to self-destructive behaviors; and people can harbor wounds from living in a world disconnected and destructive of nature. In addition nature is also the curative place and a source of metaphor for healing (Rozak, 2005; Roszak & Ajhar, 1993). Ecopsychology incorporates ecology, psychology, and systems’ ideation within a therapeutic model in order to help individuals understand the self in relation to life’s web. *Ecopsychology* strives to help participants improve themselves along with the environment (Feral, 1999).

The reason I introduce these concepts is that each year that I teach Environmental science (this will be my seventh) I see a pattern repeat itself. Students begin with a typical level of scientific interest as we begin the year with the study of ecology and its interactive systems. Their excitement seems to peak when they learn “fun facts,” as they like to call them, about extraordinary symbiotic relationships or adaptations of organisms with in ecosystems. However, as we move into the complicated realm of human interactions in this system the “difficult facts” begin to emerge. Just the other day one of my students shared with me her feelings of being overwhelmed, despite her desire to know more:

> [s]ometimes I think, this is my most depressing class—even more than International Relations—and we are leaning about genocide. At least in that case I can see that it is not me, or happening here. Environmental issues are everywhere, the air, the water, our food." (High school senior, personal communication, March 7, 2005)

This is not an isolated case, David Hicks, professor at Bath University found the same thing to be true in his studies of students and educators. Students report feeling a full range of emotions from: anger, frustration, despair, indignation, cynicism and denial —to a sense of challenge and excitement (1998). Indeed even Aldo Leopold felt the burden in 1947 when he published *A Sand County Almanac*. Leopold states "[o]ne of the penalties of an ecological education is that one lives alone in a world of wounds" (1966, p. 197). World renowned biologist Dorian Sagan puts it more bluntly; "Our ability to tap into earth's resources to power our own growth has brought us to something even more annoying than the brink of collapse of population or standards of living; it has brought us face to face with our own stupidity" (1997, p. 16).

What a solution-based education is trying to foster is pulling our minds out of denial and moving into action. Practicing the arts of biomimicry and sustainable living attempt to work to quell the cognitive dissonance between what we do on a daily basis and what we know. It is essential to limit this dissonance between our society and our beliefs, so that students (and teachers) can feel empowered, excited and proud (Huckle, 1990; Hicks, 1998).

One can look in any environmental textbook or read from a litany of respected authors and the facts reveal a grim story. Jane Goodall (1999), respected scientist, world traveler and inspirational speaker even claims, "Sometimes it is hard to be optimistic" (p. 229). She says, "Indeed, environmentalists have produced terrifying statistics that "prove" that life on planet earth is doomed, statistics computed from the rate at which rainforests are being destroyed, the greenhouse gases building up, the human population growing, and so on" (p. 232). Too much fear can block the absorption of knowledge and denial and withdrawal can be the self-defense mechanism (Tapia & Blochmann, 2000). Indeed "denial is an understandable response to the enormity of environmental and global issues" (Hicks, 1998, p. 167).

I held onto an essay of a student that I taught in my first year who so eloquently admitted what everyone in her class seemed to be thinking. "Some days I am so thankful that I have woken up from my slumber and I understand what is going on and all the connections around me; and other times I just wish I never knew—I could just get in my big car and drive to the mall without any thought. I guess that is why they say *ignorance is bliss*" (High school senior, personal communication, 1998). Many ecopsychologists and authors correlate this "psychic numbing" that society seems to induce with a need to cope with the disconnect between our daily actions and our perceived needs along with their rippling outcomes. (Feral, 1999; Lappe & Lappe, 2002; Sewall, 1999).

As environmental educators we cannot simply teach one side of this environmental story-- the loss. We need to balance out the losses with small victories. We cannot simply overwhelm pupils with the world's problems; we should teach in a spirit of optimism (Huckle,1990 in Hicks, 1998). "No problem, environmental or otherwise, should be taught about at any level of education without concomitant emphasis on positive strategies for its resolution" (Hicks, 1998 p. 173). There is hope, and there are people finding solutions to the problems of our time, often rendering the mundane both exciting and promising. Once we—as learners—complete the difficult step of owning the difficult information, and recognizing our "thought traps" it is then time to turn empathy into action, and feeling of being overwhelmed into optimism (Lappe & Lappe, 2002). Solution-based education seeks to cultivate this shift. Biomimicry looks to nature with care and awe while at the same time seeking solutions for ourselves.

> That concern for something Other, something better, something not yet, is an inherent element in the human condition and one of the deep components of human creativity. It is hope which allows us to go on when conditions look bad or even impossible. It is hope which keeps possibility open. (Hicks, 1998 p. 167)

"Biomimicry is hopeful, in that it affirms: there is a way to sustain diversity and plentitude of organisms on limited resources- nature does it every day" (Powers, 2004, p. 3). It is essential to integrate environmental success stories into our curriculum and cultivate awareness of sources of optimism, there are people making changes for the better and there are new and appropriate technologies which can offer liberation (Huckle, 1990, cited in Hicks, 1998). Jeremy Eddy, who now runs the *Biomimicry Curriculum Project*, states:

> [B]iomimicry, [is] a potentially far-reaching framework for teaching biology and design principles. Presented with interesting, contemporary design challenges, students will naturally be motivated to look deeply into nature's mechanisms, to become admirers of species ranging from sea fans to elephants, from amoebas to willow trees, in search of insights. (2004, p. 4)

Education must take a major role in preparing students for the work that lies ahead to resolve our societies' conflicts with itself and the natural systems which support life. "Ecological Education is not just about biology, it is equally about the deeper causes of biotic impoverishment, which have to do in one way or another with political behavior, institutions, and philosophies. Conservation biology is a dialog between science and political action" (Orr, 1994, p. 73). Education must be more than facts and figures. It requires a difficult look at ourselves and our behaviors. It requires science to hold hands with ethics and discussions of morality. Indeed science alone can be dangerous, as David W. Orr, professor of Environmental Studies at Oberlin University points out (1994) that most of our environmental dilemmas from toxic waste disasters to photochemical smog are the result of the ingenuity of highly educated people. He associates the perpetrators of the current ecological crisis with those of the Holocaust:

> Elie Wiesel once made the same point, noting that the designers and perpetrators of Auschwitz, Dachau, and Buchenwald- the Holocaust- were the heirs of Kant and Goethe, widely thought to be the best educated people on earth. But their education did not serve as an adequate barrier to barbarity. (p. 7)

According to the National Forum on Partnerships Supporting Education About the Environment's (National Forum…) Report (1996) the first goal of learning is to impart knowledge. But there is much more to education. Other equally important goals are the teaching of skills such as problem solving, conflict resolution, consensus building, information management, interpersonal expression, and critical and creative thinking. "Education encompassing the concepts of sustainability offers an exemplary vehicle for developing and exercising many of these skills which are increasingly being sought by employers" (National Forum, 1996, p. 5).

Healing at any and all levels and the understanding of interrelationships is empowering. A student from a school participating in an academic program that used environmental based education as its fulcrum commented: “Now, I find myself trying to make connection in everything I do. It’s a subconscious thing that happens. After you learn this way for two years, it just comes naturally” (Liebermann & Hoody, 1998, p. 8).

Once we face the difficult realities of what we have been a part of and realize the relationships the true solutions start to unfold before our eyes and that is exciting and empowering. (Hawken, as cited in Lang & Springbelt, 2003). The scientific marvels pale in comparison to what nature does each day. Biomimicry provides the ideal guiding principals to apply to our actions and open our eyes. Not only are the solutions to material problems all around us, such as better functioning adhesives or more durable surfaces, but they also can provide farther reaching solutions as well. Not only are they better in the direct function they might provide, but they do deliver their products in life-friendly ways. In other words, in order to achieve a means in nature, the ends do not result in air, water and land pollution. They do not continue to leave a chemical legacy in our environment and in our bodies. “Bringing about such a sustainable culture will require the best efforts of eco-pioneers from all over the world who are experimenting with or reviving techniques that allow humans to provide for their legitimate needs without doing substantial harm to nature.” (Lerner, 1997, p. 387).

Summary of Literature Review

Environmental Education seeks to teach people a sense of connection to the natural systems around them and the scientific principles which guide these systems. Ecological literacy combines a mission of imparting knowledge with skills in critical analysis, problem solving and systems thinking. These proficiencies are critical tools for working towards a sustainable future; a future in which upcoming generations may enjoy things that are familiar to us, such as an abundance of species, clean air, and clean water. Biomimicry is a paradigm shift in thinking which can be applied to everything from the manufacturing of specific products inspired by nature to the organization of businesses modeled after a type III ecosystem. The high school classroom curriculum around biomimicry supplies excellent material for integrated learning and problem based learning. The solution centered focus provides hope filled explorations of environmental science's otherwise complicated and troubled conclusions.

PROJECT OVERVIEW

Biomimicry is a concept that needs to spread among educators and among the public in order to become an integrating concept in learning and decision making. There have not been any studies about biomimicry in the classroom. Only a few educators who have learned about this concept have attempted to integrate it into their curriculum. In my project I plan to create a website which can serve as a resource for teachers and professionals interested in biomimicry. This website will provide information available to anyone about:

- Examples of biomimicry for lessons and understanding
- Curriculum ideas
- Resources
- Posting of trainings or meetings about biomimicry
- Links
- Important contact information and ways of networking

EXAMPLES OF BIOMIMICRY

Biomimicry has long inspired humans in our inventions. Native American's used to watch what the bear ate in order to learn about new food sources (Benyus, 2002). Originally we may have borrowed directly, a fur from an animal to act as a coat, or feathers to decorate ourselves but now we may be at a time in history when our technology can not only allow us to unwrap the mysteries of how nature provides these things, but how can mimic these provisions as well. Some well known modern day inventions include Velcro inspired by weed seeds that catch in your socks, to the life saving hypodermic needle, inspired by snake fangs (Robbins, 2001). This section will discuss a few illustrating examples of biomimicry to help the reader gain full understanding of the ideas at play. Additionally a more extensive example list is provided in Appendix A. Included are examples of how a material can be borrowed from nature and also how a process can also be apprenticed because it is important to illustrate how globally this conceptual framework can be applied.

Biomimicry of Materials

Duplicating materials created in nature is not always straightforward. There are many natural materials that have inspired scientists to endure painstaking research in an attempt to recreate them. Scientists already admire the product, now they need to uncover the mystery of just "how they do it." Two famous and student-friendly examples are spider web silk and gecko toes. The two in combination make any fan of Spiderman realize that fiction could soon be reality and nature has all the answers waiting.

Spider Dragline

Perhaps it was E.B. White's endearing children's story of *Charolette's Web* (1974) that first started an appreciation for the art of spider webs, but people have certainly been borrowing from their design for a long time; just look at Native American dream catchers or a fisherman's net. However we are now getting down to an appreciation for the silk at a molecular level. The silk of the golden orb-weaver spider (*Nephila clavipes*) is 30 times thinner than human hair. And yet if we extrapolated its characteristics to a size we could picture, say a dragline half the diameter of human hair, scientists calculate this fiber could hold two medium sized people (Valigra, 1999.)

This spider silk is five times as strong as our best comparison, Kevlar which is used in bullet proof jackets (Benyus, 2002, p. 132). Not only does it rival the strength but it is more elastic and lightweight. To make Kevlar we use petroleum-derived molecules treated in a pressurized vat of sulfuric acid at temperatures of several hundred degrees Fahrenheit (Benyus, 2002, p.135; 2001), Using conventional manufacturing techniques we may create many amazing products; however, in the balance we require extreme amounts of energy and create bi-products that are often hazardous to handle, store and dispose. The spider manages to make its superior fiber at body temperature, without requiring high pressures or corrosive acids (Benyus, 2001).

It is difficult to underestimate the breadth of new applications that would be enabled if humans were to be able to produce a material with properties approaching those of spider silk. In addition to being strong spider silk is also highly elastic, a combination that is rare in one material (Benyus, 2001). Silk can actually stretch 40 percent beyond its original form and bounce back. That is 30 percent further than our stretchiest nylons (Benyus, 2002, p.132; 2001).

Dupont researchers say that compared to current steel cables currently in use, dragline spider silk one fourth as thick could stop a jet in flight on an aircraft carrier (Valigra, 1999). As Richard Lipkin reports (1995) “spider silk is so strong and resilient that on the human scale, a web resembling a fishing net could catch a passenger plane in flight. If you test our strongest steel wire against comparable diameter silk they would have a similar breaking point. But if confronted with multiple pressures, such as gale-force winds, the silk can stretch as well; something steel cannot do (Benyus, 2001, 2002). For the spider this is necessary in order to catch its prey which may hurtle themselves unwittingly into the web at top speeds, and then fight for its life to get free. This trampoline effect effectively captures prey while keeping the integrity of the web intact. Therefore it is easy to imagine if that produced at the correct thicknesses spider silk would make a superior material to use on suspension bridges as well as reflecting bullets off vests.

Another fabulous characteristic to add to the list of synergistic qualities of spider silk is its tolerance for cold temperatures. It has to get extremely cold before it becomes brittle enough to break easily. Spider silk’s low temperature properties give additional validity to its potential as a superior material for bridge cables, but also has implications for lightweight parachute lines which can often encounter frigid temperatures. Scientists are also dreaming of its applications in smaller elements such as sutures and artificial ligaments (Benyus, 2001) or wear-resistant shoes and clothes (made of “natural fibers”) stronger ropes, nets, seatbelts; and rust-free panels and bumpers for automobiles. (Lipkin, R., 1996).

Christopher Viney, researcher of the golden orb weaver says we have to become spiders’ apprentices “if we want to manufacture something that’s at least as good as spider silk, we have to duplicate the processing regime that spiders use” (Benyus, 2002, pp. 135-6). Indeed it is amazing. Spider silk begins with a liquid protein in the abdomen of the spider. The raw material then travels from this gland through a narrow duct and it is then squeezed out through one of six spinnerets (or minute nozzles at the spider's back end). What goes into the spinneret as soluble liquid protein (a la a lunch of insects) "emerges an insoluble, nearly waterproof, highly ordered fiber" (Benyus 2001).

Each spider can construct multiple types of silks, some for structure, such as the dragline, used for repelling and framing a web; other silks are for stickiness, cocoons, mating, and more. However, all of our current scientific knowledge comes from studies of only two kinds of threads spun by fewer than 15 species of orb weavers, a subset that makes up only one tenth of more than 40,000 spider species. Certainly it begs the question, could there be an even better silk out there? In deference to this question Viney admits that most research begins with what is easiest, what others have already done, or the simplicity of care of the organism. "But yes there is probably a tougher, stronger, stiffer fiber being produced right this minute by a spider we know nothing about. A spider whose habitat may be going up in smoke" (Benyus, 2002, pp.138-40).

Biomimicry is more than learning about the tiny workings of nature and looking at each of the parts; we must also look at the entire organism and the systems it is a part of. Looking to nature for solutions is not simply about having a better material at our disposal but also learning the lesson that we need to maintain ecosystems as a library of ideas. Both the potential new material and the side effects of its production are of equal importance. In using biomimicry as a paradigm, the solutions and the resources are of utmost importance, and they are one in the same.

Geckos Toes

If you have ever traveled in the tropics you have probably indulged in a moment of fascination as you watched a gecko sneak across your ceiling. A welcome bug eating visitor, they can skitter across any surface: smooth, rough, wet or dry. Even Aristotle commented on their dexterity and ability to “run up and down a tree in any way, even with the head down-wards” back around 350 BCE (as quoted in Autumn & Peattie, 2002). More recently, researchers have been employing biology, physics, chemistry, and nanoscience to try to solve the mystery; is it suction, friction, chemical bonding, water-based capillary adhesion or hydrophilic interactions with van der Waals dispersion forces (Ben-Ari, 2002). The question has finally been answered and the results are fascinatingly ‘fuzzy’ feet.

The pads of the Tokay gecko (Gecko gecko) used in the studies of Autumn and Peattie (2002) are covered with modified layers known as lamella:, each of these is then covered with similarly oriented tiny hairs known as setae. Each seta splits into as many as 1000 branches with spatula shaped tips, or spatulae, measuring a mere 200 nanometers wide. Although the energy from van der Waals interactions is weak, the billions of setae tips create such a vast surface area and they are able to nestle so closely with their target surfaces, that the many weak interactions add up to a significant adhesive force. So strong in its adhesive force that “scientists calculate that a gecko’s-worth of setae, which would fit on a nickel, could lift about 250 pounds” (Ben-Ari, 2002). Another way to try and picture it: the combined charge is so powerful that, theoretically you could suspend a 90 pound weight from the gecko and they could still get across the ceiling (Robbins, 2001). Therefore in trying to duplicate this wonder scientists concentrate on “the smaller the hairs are, and the more of them you have, the greater the adhesion.” (Ron Fearing, engineer at the University of California, Berkeley, as quoted in McDonagh, 2003).

Now one might consider that many of our adhesives could hold up a gecko; but what is even more fascinating in this story than the adhesion is the complimentary ability to detach. These tiny hairs made from β-Keratin, are a versatile substance used in many of nature’s creations, from hair and nails, to scales and whale baleen. This life-friendly substance is not only able to create a structure that can stick to any surface but can just as easily detach without leaving a mark. Autumn & Peattie (2002) found that it is all about the angle of the setae that allows for traction, and yet infinitely close to the angle in which the force is broken, allowing the gecko to simply change the angle of their foot to release.

For biomimics the real question is what do we do with this knowledge? The implications for manufacturing are already being researched. Even a non-scientist or business person can dream of the applications of a dry adhesive that can be used and reused like Velcro, but without the need of an opposing side. An extremely versatile adhesive indeed, gecko technology can be used on any surface, even in a vacuum or underwater. Not only that, it is clean and reusable (McDonagh, 2003) because it would work without leaving a residue or picking up dirt (Ben-Ari, 2002). Certainly it could be used for the commonplace for things like, hanging up art like giant Post-its™ without harming the paint job, closures on packaging or clothes, even Band-Aids™ that would not hurt when its time to take them off. It also has safety implications for safer tiers, or sutures (Stroh, 2003). However the more adventurous minds quickly start to have Spiderman fantasies. Indeed Professor Andre Geim, Director of the Manchester Centre for Mesoscience and

Nanotechnology has been able to make one graduate students' dream come true as he "hung out the window of a tall building" using their aptly named Gecko tape (2003).

Like the pads of its inspiration this tape contains billions of tiny fibers less than a micrometer in diameter. The 1 cm^2 prototype patch can bear 3kg: that is about 1/3 of the weight of a similar area of Gecko sole (McDonagh, 2003). In addition, the Gecko tape begins to lose its adhesive qualities after about five applications. Geim blames this shortcoming on polyamide's hydrophilicity (the plastic's tendency to attract water) as compared to the hydrophobic qualities of protein-based true gecko setae (McDonagh, 2003). In other words, the hairs get soggy and can clump together where as the fibers of Gecko's keep water and dirt off. Scientists are still trying to live up to the abilities of these tiny creatures and therefore currently the application of this new tape is being kept to smaller things on the market like a Gecko toy, but this is only the beginning. Bob Full from Berkeley University commented. "Geim's development is very exciting, as uses for the tape are nearly unlimited. In addition to a general adhesive, it can be used to move computer chips in a vacuum, pick up small fibers, and design novel bandages." (Manchester Center for Mesoscience and Nanotechnology, 2003).

Perhaps these biomimics need to take the next step in biomimicry and look at the natural materials and processes that are able to create these fascinating surfaces without the use of limiting petroleum based plastics. "Businesses should work like a living system…they should find a way to create conditions conductive to life, not toxic to life." (Benyus, 2002).

Biomimicry of Processes

Not only can researchers mimic natural materials but we can also look at entire systems for answers. How do organisms in ecosystems interact with one another? Where do they get their energy? What happens to their waste? If we ask these questions we find answers that have been a part of nature all along and provide practical solutions to human problems. What follows are examples of how we can use the concepts of biomimicry to insert ourselves back into the natural cycles and systems. One example explores food production as a basic need product, and the second looks at waste management nature's way.

Farming Like a Prairie

Since the launch of the chemical revolution and the second generation pesticides that came out of World War I military tactics, industrial agriculture, has been stuck on the "pesticide treadmill" (Miller, 2004). This treadmill of spraying for pests that eventually become resistant, which causes us to increase our chemical doses on the land, sounds akin to the cyclical chemical dependency the human body seems to face with addictive drugs. And it seems just as treacherous to extricate ones self. Once on the " pesticide treadmill soil biota that would otherwise cycle nutrients in the soil are damaged. Thereby creating a secondary dependence on synthetic fertilizers. Since 1945 pesticide use has risen 3,300 percent, but overall crop loss to pests has not gone down (Benyus, 2002, p. 18). In addition about forty percent of the soils on the planet are already seriously degraded and continue to decline (Jackson as cited in Ausubel, 2005, p. 113). Although these petroleum-based applications have long since claimed to be "the only way to feed the world," some people are looking for healing; a healing of the soil, of the well water, and of ourselves.

The Land Institute in Salinas, Kansas is a research facility and farm that is thinking outside of the traditional industrial methods and looking to the local ecosystem for lessons. It is difficult to take that first step, but like an intervention, the offender must first admit that there is a problem, and then want to find help. In other words, first we must realize that we are often more ignorant than we are knowledgeable. As Wes Jackson, Director of The Land Institute, puts it, we must “embrace the arrangements that have shaken down in the long evolutionary process and try to mimic them, ever mindful that human cleverness must remain subordinate to nature’s wisdom” (p. 11). “Essentially we need to farm the way nature farms” (as quoted in Benyus, 1997, p. 21.)

The impetus to begin agricultural research at the Land Institute was inspired by the critical issues of soil erosion. A quarter to a third of our topsoil is now gone, only 200 years after opening this country to agriculture (www.thelandinstitute.org). After a good storm sweeps across the plains a drive around often reveals damaged plants and soil running in rivulets down roads around traditional wheat farms. However if one takes a field trip to an intact prairie, one will find most of the water absorbed and the plants still standing. Studies revealed that there are eighty-eight times the run-off from a typical Kansas wheat field compared to an intact prairie (Benyus, 1997, p. 25).

What they realized at the Land Institute was that industrial agriculture has long depended on *annual monocultures,* or growing fields and fields of one type of short lived crop. Although we can create machinery that is adapted to our specialty crop and focus our marketing energies on one product the limitations of this model are revealing themselves, and they are extensive. The Land Institute began studying the prairie’s *perennial polyculture* model and found that besides being great sponges they were also “self-fertilizing and self weeding.” (Benyus, 1997,

p. 25). They wanted to see if they could apply the prairie's principles, and gain its advantages, while still producing desired crops (Jackson, as cited in Ausubel, 2005, p. 110).

When they looked into the prairie system they found that by creating a similar polyculture, or mix of plants including 1) perennial grasses, 2) legumes, 3) sunflowers, 4) grain crops, and 5) plants with natural insecticides grown together in one field they reaped many of the natural benefits. The first benefit was improved soil integrity and health. This stems from the natural nitrogen-fixing adaptations of legumes (their roots systems attract natural soil biota to create nitrogen fertilizer for plants). This chemical "fixing" process is provided "free-of-charge" by symbiotic soil bacteria. However, in monoculture farming. Fixing must be accomplished manually as soils are rendered "dead" by loss of top soil and a chemical load. The manual nitrogen-fixing process utilized in modern industrial agriculture requires the extensive use of fossil fuels. Jackson has calculated that we use 1.8 times as much energy in fossil fuels in order to create this same nitrogen fertilizer, than in than all tractors and farm equipment combined (Jackson as cited in Ausubel, 2005, p. 109).

In polyculture systems the root integrity of perennial, or multiple season plants, is able to use the soil fertility more efficiently because various plant species have different root depths in which to capture nutrients (Miller, 2004, p. 277). Although part of the root systems always remain intact to hold in soil, thirty percent of the roots die and decay each year adding additional "free" fertilizer in the form of organic matter to the soil (Benyus, 1997, -25). These plant communities are efficiently recycling their phosphorus, potassium, manganese, and other nutrients (Jackson as cited in Ausubel, 2005, p. 110). Healthy root and soil systems foster fungal symbiotic relationships in which mycorrhizae extend the roots ability to absorb water and nutrients ten to a hundred fold and increase soil water holding capacity (Stamets, 2005). Unlike annual fields that are periodically plowed leaving exposed soil, the perennial root systems hold soil and prevent erosion in wind and rain. In addition using hardier perennials gives more resilience in dry spells as well. This combination in itself maintained topsoil and removed the need to use fertilizers on their crops. This would indicate a huge time, energy and money saver.

Having the mix of various plants is the prairie's natural defense against weeds and predators. It seems "diversity is the cheapest and best form of pest control" (Benyus, 2002, p. 26). All available space is used and divided up by the various species living in their dynamic balance. Therefore, there are no open spaces for weeds to inhabit. In monocultures, plants are placed in rows with cleared spaces of open soil around them. This open area continues to get the same sun and fertilizer as the desired crop plants, therefore it is a constant battle of herbicides or labor to keep the weeds at bay. The thought is that weeds will compete for nutrients and water, which is why farmers space their crops and use herbicides. However in the thicket of prairie plants the time tested natural systems have worked out partitioning of the resources; blooming at different times and having root systems of varying depths.

In addition the multiple plant types provide various smells and signals, both attractive and detracting for insects. The implications of this are that there are various habitats supplied for natural predators of the crop eating insects, and the fields will not attract the same damaging level of pests due to the mixed cues and forage. Where as annual fields are acres and acres of the same crop advertising its abundance to specialist pests. (Miller, 2004, p. 284; Piper as cited in Benyus, 2002, p. 26). In addition the diversity of plants and diversity of genes helps insure a natural defense against disease as well. When all seeds are genetically homogeneous then farmers become very vulnerable to one disease wiping out entire crops (Miller, 2004, p. 295).

Today most of our calories come from only about 20 species of plants, all of them annuals (Benyus, 2002, p. 26). Of the 30,000 edible plants, we still gain over half of our calories from only three, wheat rice and corn (Miller, 2005, p. 278). And the UN estimates that two-thirds of all seeds planted in developing countries are of uniform strains (Miller, 2005,p.295). The Land Institute's research has show that it is possible to get equivalent productivity out of perennial plants grown in a polyculture setting. Certainly we need to get creative about our harvesting practices, and retire the machines that sewed seeds in rows and harvested monocultures. In addition labor and money are ultimately saved from the new freedom from chemical fertilizers, herbicides and pesticides, while the topsoil is maintained for generations to come.

As amazing as the findings are prairie polyculture cannot, and should not be broadcast to all agricultural areas, because not all areas are prairies. "Natural systems are interconnected in such an intricate pattern that the idea that you can just put anything anywhere is terribly destructive. Yet, in many ways, we've based our whole culture on it." (Barlow as cited in Jenson, 2002, p. 8). However, the biomimicry paradigm is easily exportable. Instead The Land Institute would encourage people to look at the what nature is doing naturally in their area and use its lessons to amend farming practices to better integrate them with the land (Benyus, pp. 35-6). And indeed it is beginning spread; there is a permaculture movement sweeping Australia, and Masanobu Fukuoka's "Do-Nothing" rice farming techniques from Japan springing up all over Asia, (Benyus, 1997), shade grown coffee replacing traditional plantations and restoring rain forest, and Dan Daggat's rangeland restoration with cattle in America's west, just to name a few (Ausubel, 2003).

In addition to helping the soil, water and land within the local area of the farm, this type of farming paradigm has much more broad-reaching implications. Perennial polyculture has the potential to reduce the chemical load that affects farm workers health, and is re-circulating and biomagnifying through natural systems and through mothers and breast milk. In addition, it has the potential to reduce our dependence on oil and natural gas. Oil is used to run our farming equipment, ship our food around the world, and is refined into our fertilizers and pesticide products. Looking locally for answers and for food reduces this burden. The Land Institute runs its tractors on the sunflower seed oil found yielded in its polyculture. Seed diversity is increased as farmers return to breeding seeds adapted to local conditions. These biomimics are seeking solutions to feed our ever bulging population in a truly sustainable way.

Cleaning WaterLlike a Marsh

We live on a planet in which water covers 71% of the Earth's surface. It would seem that there is plenty; however only a tiny fraction of this water is available to us for drinking, washing, industrial processes and agriculture. About 97.4% of the world's water is too salty for our uses, and of the remaining 2.6% most is frozen or inaccessible. This leaves our global population of over 6 billion and all of the other terrestrial and freshwater organisms on Earth to use the 0.014% fresh, usable water (Miller, 2004, p. 314). With all of our uses of water, it is very important that we work to reduce the pollution of our limited supply. The World Heath Organization (WHO) estimates that 3.4 million people die of water-related illness world wide (Miller, 2004, p. 484). Cleaning out water is critical to the health of our ecosystems and ourselves.

In the early 1980's a marine biologist named John Todd found that his family had to buy bottled water because the local tap water was unhealthy. He realized that if he had been cleaning water for his fish farm with tomatoes and lettuce plants he could "bloody well learn how to purify water for people" (Lerner, 1997, p. 48). "From an engineering point of view, modern sewage treatment is expensive and fairly sophisticated. It is symptomatic of a disconnected culture. Why not instead view wastes as resources out of place?" (Todd as quoted in Ausubel, 2003, p. 23.)

Ecologist John Todd, of Ocean Arks International, and The New Alchemy Institute, is creating innovative waste water treatment facilities using "living machines." From the outset he recognized that nutrient-rich waste which can be environmentally destructive if not managed, is problematic because it is an overabundance of a resource to aquatic life. If sewage is released untreated into water systems it disrupts the ecological balance and creates incredible algae blooms, which trip off a series of effects known as cultural eutrophication resulting in a dramatic decrease in dissolved oxygen and subsequent animal death. Human sewage is especially nutrient rich because unlike cow stomachs we are very inefficient at digesting nutrients (Lerner, 1997, p. 49).

Todd's ecological purification system begins with the raw sewage entering a passive solar green house or outdoor area containing tanks inhabited by a complex community of organisms. These tanks are then connected to a system of other tanks each with their own ecosystem specializing in a particular phase of decomposition and breakdown of organic and inorganic matter in the water. After spending ten days in this filtering series of ecosystems the water flows clear into an artificial outdoor marsh or wetland to be reintroduced into the local hydrologic cycle. The water can also be rendered drinkable by using an ultraviolet light or by passing the water through an ozone generator (Miller, 2003, p. 483).

Todd, an avid observer of nature found inspiration exploring the tide pools and wetlands of his Cape Cod home. "What I learned of various ecosystems, the more I perceived their ability to self-design, self-organize, self-repair, and self-replicate" (as cited in Ausubel, 2005, p. 20). He began studying filtering species from around the world. Each plant, fish, snail, or zooplankton species provided a lesson and lent a gift to the process. Rushes are able to filter out suspended materials, other plants sequester (absorb) toxic metals such as mercury and lead, others secrete natural antibiotics to kill pathogens.

Todd's living machine's filter water for companies such as Ben and Jerry's™ and for townships such as Providence Rhode Island. They can be constructed for single buildings, such as the Environmental Science building at Oberlin College, or be made as movable "rafts" to clean up a polluted pond or lake.

> Ecological machines are in many ways like ordinary machines. Like all machines they are intended to do work. But the difference between the eco-machine and the inert machine is that the living one is made up of hundreds, occasionally thousands, of species of life forms ranging from microorganisms to mollusks, and fish to higher plants, including trees. All these species work together symphonically as part of a dynamic integrated system. (John Todd as quoted in Ausubel, 2005, p. 20)

Not only are these living systems cleaning waste water without using harmful chemicals, but they are living growing systems. Selling ornamental plants, trees, and baitfish which grown ecstatically in the systems help reduce the costs (Miller, 2004, p. 481).

These “constructed wetlands” can be produced in low tech manner such as those Mark Nelson is developing to treat raw sewage from hotels, restaurants and homes in developing countries where it is often otherwise dumped directly into the ocean or shallow holes (Miller, 2004, p. 506.) Natural environments can also be use if natural appropriate wetlands would already appear. Some townships are adopting constructed wetlands models, such as the one in Arcata, Ca. which won the 1987 Government Innovators Network award for construction. In the 1970’s this growing coastal town found itself faced with a state mandated water treatment plan costing over fifty million dollars. Instead they decided to use the money to treat their sewage more efficiently and at the same time restore a damaged local wetland. Their “treatment pond” is now the 170 acre Arcata Marsh and Wildlife Refuge which is a popular local recreation site and attracts 80,000 visitors a year. There has been a reported increase in wildlife, especially birdlife returning to the area and both the commercial and recreational fisherman have noticed increased productivity of the local salmon fisheries (Harvard University, 2005).

From what we need to consume to what happens to our waste. In all steps of our economy and our lives we need to recognize that in spite of all our technology, including controlled climate cars, we are still part of the systems of nature. We need to look to nature to be our guide. We need to ask “what would nature do?” (Benyus, 1997) and then we need to be curious, open-minded and humble. Above all, we need to be willing to admit our mistakes and change for the better.

CURRICULUM SUGGESTIONS

"we can attempt to teach the things that one might imagine the earth would teach us: silence, humility, holiness, connectedness, courtesy, beauty, celebration, giving, restoration, obligation, and wildness" (Orr, 1994, p. 52).

Biomimicry has the potential for integration into many disciplines and at many levels of teaching. On a basic exploration of the wonder of nature in the elementary school years; through integrated projects in environmental science, biology, and art classrooms in high school; to architecture, design and business schools (Eddy, 2005). Biomimicry combines lessons in the basics of ecology and biology while at the same time inspiring creativity and solution based thinking. As Zenobia Barlow, Director of the Center for Ecoliteracy points out, "learning thrives when it's centered on real-world projects" (Jenson, 2002, p. 6).

In this section I will introduce two lesson plans that I have used involving biomimicry in the high school classroom (more resources can be found in Appendix B and on the accompanying website: www.biomimicry.net). These lesson plans are to serve as samples that can be used or modified. Certainly not all teachers or students are expected to know all the answers ahead of time. These are thinking exercises and open-ended problems. It becomes a powerful lesson when the teachers can let go of being the experts and let the students find the answers on their own (Barlow as cited in Jenson, 2002.) Like the examples above, this is certainly not an exhaustive list of ideas but only a representation of two very different ways to integrate the biomimicry concepts into teaching.

Introduction to Nature's Amazing Design: An Exploration of Artifacts

Unit concepts:

- Animal and plant adaptations
- Technology

Learning Objective: By having students use all of their senses and their knowledge about artifacts from nature, students will recognize the amazing adaptations and design plans that occur in ordinary objects. Students will use creative teamwork to develop original ideas for biomimicry and therefore further develop an understanding of the concept.

Materials/Prep: A set of artifacts from nature, one for every 2-4 students. If possible set the room up in a circle. Examples: animal vertebrae, pine cone, butterfly, barnacle shell, abalone shell, egg shell, seed pods, crab claw, etc.

Lesson Format: The teacher begins with one artifact and asks students to brainstorm on the many jobs this object performs and how it is designed to accomplish its jobs. The teacher then explains biomimicry and asks the students if they can think of any application of the object's design for the mentioned design problems we have in our lives.

Students are then paired/grouped and given a unique artifact for each group to discuss in a similar manner with their group members. The teacher should circulate around the classroom in order to help students with questions about less familiar artifacts, ask thought provoking questions and find out what the students are thinking. The class then comes back together and each group (or volunteers, depending on time) will share their ideas with the rest of the class.

Assessment: Primary assessment occurs as teacher circulates among the brainstorming groups. The teacher can help individuals with clarification at this point. Final assessment is evaluated when students present their findings to the class.

EXAMPLE: A deer vertebrae is designed to be protection, but also needs to allow for access of nerves in and out of the spine; It is also support for the body and a connection point for muscles; it needs to have great articulation to be able to move in many ways. It is also a used for storing minerals, and is built of natural materials at body temperature. We could be inspired to build robot parts with such multi-functionality. We could also be inspired to create molds for products out of life friendly materials (and not heat, beat and treat it, or have unwanted waste left over). In addition we could make a chair that can supply this much support but also be moldable and moveable to our position or mood.

Green City Design Project

> [P]racticing environmental engineering successfully requires a working knowledge of a wide variety of ecosystems. From the study of lakes one can learn about nutrients, energy flows, chemistry, and the dynamics of liquids. From the rain forest one can learn about diversity, the portioning of light, and the way many different life forms can efficiently share a complex, quickly changing environment. There is nowhere better than the tropical rain forest to study nature's pathways of decay and transformation. From the northern forests I have gathered an appreciation of the exquisite relationship of geology and bedrock to soil, and the way in which higher plants negotiate these interactions. Two entirely

> different ecologies and their radical variation may exist within a short distance of each other because of subtle differences in the minerals of the soil. In deserts, which are environments of extremes, ecological processes are easier to read because plants and animals are more spread out. Various forms of life are starkly etched on the landscape, and sometimes this starkness clearly reveals patens and illuminates the mechanisms of ecological organization. (John Todd as quoted in Ausubel, 2005, p. 19)

<u>Unit concepts</u>: (I use this project as a culminating activity to integrate units learned throughout the year).

- Urbanization and transportation
- Population growth
- Biomes
- Water use and watershed
- Adaptations
- Energy
- Land management
- Waste management

<u>Learning Objective</u>: Students will design a city using sustainable principals. Students will understand the complexities of city planning and all the overlapping economic, sociological and environmental needs. In addition not all solutions should be universally applied; we need to look to nature locally to find local answers. (For example challenges and solutions may be different in Miami verses Chicago).

Materials/Prep: Large paper (butcher paper or poster boards) and colored markers

Access to the Internet

Teacher may want to bookmark helpful sites ahead of time

Lesson Format: Students are put in groups of 3-4. I open with a dramatic introduction: "there has been a major disaster and you have been hired to redesign the city from scratch." Each group is given a city and asked the following questions: 1) Find out the natural history: topography of the area, the local climate, and biome factors. 2) Research one native plant in the area. Why is it so well adapted to this place? How could you use some of these ideas in your city plan? 3) Research an animal that is native to the area. How is it so well adapted to this place? What inspirations can you find from this animal in the design of your city? 4) Make sure you include, how the city acquires energy and water, what they do with waste, what is the transportation plan, where do people live? Work?

Time: Three 50 minute classes or homework and a double block.

If students have selected their area they can divide up research tasks for step one (either in the first class period or for homework). One student can look up climate and maps of the area, another student can look up information on adaptation of plants and the third student can research the adaptations of a local animal to the eco-region/biome.

Then in class students can agree on the city plans addressing the questions above and draw a diagram to represent their ideas. Students then present in the third period/ second half of double block.

Assessment: Students present their city plans to the class. Classmates ask questions about decisions made by each group.

EXAMPLE: Student group one selected Phoenix Arizona. In researching this city they find that it is in the desert. They select the saguaro cactus and the kangaroo rat as organism inspiration. They find that the Kangaroo rat makes its home underground to keep cool during the summer days and warm on winter nights. The kangaroo rat also keeps all water possible and has adapted a means of processing urine which does not require water loss. The saguaro uses the sun to acquire energy and collects water during monsoon storms and stores it for later.

The new city takes inspiration from the cactus and is able to use solar on all building roofs this can take care of hot water heating and most energy requirements. There are also back up wind farms (deserts are known for wind) and a biomass generation plant. Like the burrows of the kangaroo rats, homes are built with thick stone/adobe walls or as partial earth homes to maintain cooler temperatures without as much energy hungry air conditioning. Overhanging eves are used to keep midday and summer sun from heating home through windows. Also inspired by the kangaroo rat all water is conserved and reused as much as possible. All water in homes is on a grey water separation system in which water used for cleaning (sinks, showers, washers) is recycled and used to water the garden and home plants. Gardens use xeriscaping with drought-tolerant, native plants. Therefore they need little to no watering. Residents are encouraged to compost food scraps and create natural amendments for their gardens with low organic desert soil. Local farms and home gardens use drip irrigation at night.

There is a light rail system around the town and safe bike paths are built throughout the city. There are some shopping districts which are pedestrian only. There is a rail stop near homes and homes, and if people must drive the parking structure has many floors to keep cars shaded and even the top has a solar paneled roof to both provide surface generation of power in addition to shade. Apartments are located near and above shops so that many people can live and shop in one location. The city recycles everything.

SUMMARY

Biomimicry seeks solutions to all of our needs and aspirations by looking to nature as teacher. Billions of years of evolution have worked out solutions to problems quite expertly. Now is the time when we need to start shifting from simply taking resources from nature, and instead begin borrowing ideas and systems also. Students of environmental science quickly learn about all of our human mistakes and the dilemmas of our growing population on a finite planet. However, Biomimicry encourages a perspective shift by transferring to creativity and ingenuity, revealing solutions and sustainability.

APPENDIX A: Examples

This table is to be used as a resource for inspiration and informative tid-bits to add to lectures, lessons and discussion.

Table of Biomimicry examples

NATURE'S DESIGNS	INSPIRATIONS in the WORKS
Hooks on burrs and other seeds	Velcro-one look at your socks after a walk and you understand this biomimetic invention.
Abalone and conch shall nacre (mother of pearl coating)	Consists of alternating layers of hard and soft material so cracks in hard is absorbed by the soft. Therefore this structure self-assembles and self-repairs. Inspiration: the bodies of cars or anything that needs to be lightweight but fracture-resistant.
Ant colony network repair systems	When the colony is damaged ants are able to find a new optimal site and move resources efficiently and with limited communication. Inspiration: Information Technology and computer specialists are looking to this model to scout out damaged computers and programs in systems and quickly reroute to limit breakdown.
Antlers, teeth, bones, shells	Nature constructs 3-D objects layer by layer using common minerals and nature's blueprints. Inspiration: : ink-jet, and CAD technology .
Barnacle valve seals	Inspiration: A help for heart surgeons and plumbers alike
Bat and marine mammal navigation	We are still trying to discover the intricacies of a bat's sonar. And recent research suggests that other animals use a combination of magnetism, the sun, stars, and sight to navigate. Inspiration: Sonar, and a walking cane has been created using fruit bat sonar techniques to aid the blind.
Blue mussel adhesive	An adhesive that is able to set underwater AND can attach to any type

	of surface. Inspiration: Could transform paints and coatings, and enable surgeons to use biodegradable "glues" instead of sutures.
Blue mussel byssus (The tether attaching the mussel to a solid surface)	This collagen/silk mix uses a blended boundary between the two materials therefore getting the best of both worlds and alleviating the weak spot that occurs at an abrupt interface. Inspiration: composite material science.
Blue mussel byssus sealant	While it is active it protects the thread, but when the time frame is over it degrades allowing for the entire structure to decompose. Inspiration: Compost able cups and other dining wear.
Camouflaging Cephalopods	Cuttlefish and Octopus are able to change and camouflage with their environment using three types of color organs which allow it to create combinations of pigment and iridescence. Inspiration: changeable clothing or furnishing gives the ability to have changes with out more stuff.
Cell membranes	1) Inspiration: Desalination and chemical separation filters. 2) Specific receptor proteins in cell membranes also react to specific target chemicals. Inspiration: Scientists want to use these simple and yet specific models to create detectors that will change from blue to red in the presence of a target substance. This technology could be used to detect disease, chemical leaks and for other safety measures.
Chimpanzees	Chimps use plants with "secondary compounds" to self medicate. Inspiration: Observing wild species could speed up our search time for new medicines.
Chlorophyll and enzymes	Photozymes-chlorophyll-like molecules that attract conduct and absorb light energy. Like enzymes they use available energy (sun) to aid needed chemical reactions. Inspiration: when added to water, photozymes can break down pollutants such as PCBs into harmless compounds using the sun's energy.
Cockroach cuticle	A springy protein known as *reslin* found in cockroaches does not swell on contact with organic solvents. Inspiration: Protective gloves or

	tubing would greatly aid out handling of fuels and other hydrocarbon based chemicals.
Crab shell	Chitin, the material the many arthropods exoskeletons are made of, is an exceptionally strong biopolymer nano-fiber mix. Inspiration: Could be used for biodegradable casing, or implants that may resist rejection.
Crocodile Skin	Able to deflect spears, arrows and sometimes even bullets. Inspiration: protective clothing or coverings for cars etc.
Cyanobacteria	When there was an abundance of CO2 and Water, instead of thinking of it as waste, it was taken up as a resource of plenty. Inspiration: Scientists are now working on biodegradable plastics from CO2 instead of carbon-based petroleum.
DNA	DNA's shape-fitting and self-assembly powers allow it to solve mathematical problems that have so far stumped conventional computers.
Dolphin and shark skin, Narwhal tusk	This material deforms slightly to shrug off water/air pressure. Inspiration: Airplane or submarine hulls. Speedo™ is already looking into a racing wetsuit/swim suit design
Elastin, the elastic protein in heart muscle	Inspiration: Intelligent materials such as fabrics that stretch and contract in response to heat, light, chemical changes.
Everything in nature which balanced by the natural recycling of biogeochemical cycles	Inspiration: “Cradle-to-cradle” green products that will be designed to have no waste from the first stage of design so that they can be used, reused, and then fully recycled.
Femur Bone	The lattice structure inside the human femur bone which both allows for strength as well as circulation. Inspiration: It certainly inspired the architect of the Eiffel Tower.
Filter feeders	Inspiration: Mussels, barnacles and other filter feeders could teach us a few things about cleaning water naturally.

Fish antifreeze	Able to keep the tissue of fish from freezing in winter lakes and deep waters without harming life. Inspiration: New ways to freeze human transplant organs without injury.
Fly ear drums	Use a see-saw design to find sound directionally. Inspiration: Could support us in hearing aid design.
Food webs	Inspiration: Vietnamese permaculture model of rice paddies has a cycle of: carp, ducks, rice, snails which all now depend on one another for food and waste. The farmers are part of the web.
Forests	An interrelated system in which resource partitioning and recycling of waste with in the system allows for sustained diversity in one place. Inspiration: Farming practices and edible landscapes using multiple layers of cropping. Better ways of urban and community planning. Eco-industrial complexes.
Forest Floor	The mixed yet complimentary outlines allows for any intermixing of elements to create pattern. Inspiration: interchangeable carpet tiles which can be changed out as sections fade so that entire carpet does not need to be reinstalled.
Fruits and Vegetables	Fruits can be over 97% water and yet they don't slosh or spill because the liquid is held in a cellular matrix. Inspiration: storage of dangerous liquids
Fungi	Acting as nature's Internet mycelia mats connect forests, share nutrients, communicate information, filter water, reduce run-off and recycle matter. Mycelia are experts and breaking hydrocarbon structures, and fortunately that includes our problematic creations such as pesticides, PCB's and jet fuel. Inspiration: *Mycoremediation* and *mycofiltration* has shown promise in cleaning up everything from petroleum-based waste, nerve gas, and dangerous E.Coli
Gecko toes	Geckos are able to walk up walls and ceilings even of smooth glass using molecular van der Waals forces. Inspiration: Applications for non-marking adhesives, closures, and of course rock-climbing gloves.

Hibernating bears	Bears are able to go for months without urinating, and yet don't poison themselves. Inspiration: Clues to fighting diabetes.
Horses Teeth	Studies of horses teeth have revealed new bonding agents. Inspiration: Could help with hip replacements.
House Fly	Can hover, fly backwards, soar sideways and land upside down. Inspiration: Dexterous flying machines.
Human tongue and ear drum	A classic (Bell's) biomimetic story. Inspiration: Telephone speaker and receiver
Hummingbirds	Able to fly 35mph and travel 2,000 miles per year. They have to make long over water flights on very little fuel (600 miles on 2.1 grams!) and the process by with they fuel up pollinates, in other words, contributes. Inspiration: More efficient and biologically based fuel systems and flight technology could be discovered.
Iridescent feathers and butterfly wings	Create fabrics with structural color instead of needed dyes. Inspiration: Iridigm.com™ is using this to create PDA screens that you can read in the sunlight.
Jewel Beetle	Can detect a forest fire 50 km away using infrared pits under legs. Inspiration: Gives us clues to an infrared detector that requires no special cooling and operates at room temperature.
Kelp	Stabilized bromine coating of kelp keeps of harmful marine microbes. Inspiration: Nalco has borrowed this recipe (Staybrex™, a chlorine alternative used in plumbing. Meanwhile other red kelp use proteins, called furanons, to interrupt bacterial communication. Has applications in reducing the spread of cholera, staph and TB which are quickly producing stains resistant to our current antibiotics.

Leaves	The center of photosynthesis in plants, they are design to efficiently capture and process the sun’s energy depending on the surrounding conditions. Inspiration: "Pentads are solar batteries that mimic the leaf's reaction center. Molecular in size, they could one day be used to split water into clean-burning hydrogen gas and oxygen. Or, they could be used as computer switching devices that shuttle light instead of electrons. Or, they could be the light-activated "power packs" that help catalysts assemble and dissemble chemical compounds. Imagine doing chemistry in pure water, using sunlight and no toxins.” (Biomimicry.org)
Lemurs and many other primates	Studies of primates diets reveal that they always eat what their body needs and what is good for them. Inspiration: Lead us to nutritious native plants and medicines.
Lobster	Able to crawl along rocky shoreline without being swept away by currents and surf. Inspiration: Guide for robotics for amphibious craft, land mine clearing or space exploration.
Lotus Flower	Lotus flowers have always inspired awe for their ability to emerge from the mud a pristine beauty. Microanalysis revealed that the petal surfaces had tiny mountains and valleys that resulted in water drops picking up all dirt when it rained. Inspiration: These self cleaning surfaces have already stimulated a German paint company ISPO, to create Lotusan™ products.
Mangroves, and other marsh plants	Turn saltwater into fresh. Inspiration: Desalinization plants that are less energy intensive. Non toxic treatments of irrigation and other water pipes to prevent corrosion.
Mantled howler monkeys	Howlers regulate their own reproduction, and even the gender of their offspring, by eating certain plants. Inspiration: Can lead us to plants that have an effect on fertility.
Marshes	Act as a natural filter of water while also being a sponge to reduce flooding and a nursery for many animal and plant species. Inspiration: Constructed wetlands-sewage treatment facilities that clean a community's water while doubling as a wildlife refuge.

Microtubules	The inner lattice structure creating an “endoskeleton” for our cells. Inspiration: “Signaling array-Optic computing network which self-assembles into a light-signaling array.” (Biomimicry.org)
Namibian Beetles, Redwood Trees/ Western Hemlock	Each of these organisms has an adaptive back or needle to catch fog and transfer the water vapor into a water source. Inspiration: (Fog nets in Chile and Peru).
Native grazers	Wandering buffalo and other native ungulates used to graze the prairie while fertilizing and aiding in seed dispersal and planting. Inspiration: Managing cattle to graze and then rotate mimics the natural systems and therefore feeds cattle and can serve as restoration of habitat.
Natural disturbance	Fires and other natural disasters generate succession patterns and regeneration in forest ecosystems creating a mosaic of ecosystems. Inspiration: Forestry which follows the natural selection model mimicking a mature forest.
Natural selection	Inspiration: “Genetic algorithm software that "evolves" its own solutions, getting better and better with each generation of ideas.” (biomimicry.org)
Nautilus shell, lily bud unfurling, human pore, water down a drain (Fibonacci spirals)	The natural spiral shape has long been a favorite repeating pattern of nature and mathematics. Inspiration: Now employed as the Lilly Impellor® a fan/propeller which requires 50% less energy, 75% quieter: therefore it reduces turbulence and reduces excess heat with half motor for same size fan. (Implications: hydroelectric dams without so much fish damage, reduction space needed for computer fans, reduced energy costs)
Neurons and other kinds of cells	Our organic molecular systems are based on the lock-and-key partnerships. Inspiration: Jigsaw computing would blow our digital, silicon model away.
Old field succession/ Prairie	One grows up in the shade of another, roots with different depths, and legumes as nitrogen fixers means -no fertilizing, weeding, or tilling necessary. Inspiration: Do-nothing farming-Japanese method that sows rice, barley, and clover together in one field or modeling grass and legume varieties after native grasslands in order to grow silage for

	cattle feed without tilling, and other perennial polycultures.
Orb-weaver spider silk	Spiders are able to make multiple types of fibers for various uses at body temperature and out of food. The web constructing fiber is stronger than Kevlar while also being more temperature resistant and elastic than any material we can produce. Inspiration: Protective clothing, parachute cord, suspension bridge cables, sutures, biodegradable fishing lines and nets, safety fencing, etc.
Penguin insulation	Penguins live in the Antarctic and despite cold temperatures and major loss of body fat during nesting season they are able to stay warm using air pocket and feather networks. Inspiration: Wouldn't this be great for cold weather clothing?
Porcupine quills	These strong cylinders are both sturdy weapons and able to allow motion. Inspiration: Design could help agronomists breed better wind resistance in wheat and barley. Potentially good packaging.
Prairie dog burrows	Inspiration: Building homes into earth for natural cooling and heating. Or adobe of same thickness as burrow is deep.
Rhinoceros horn	This composite material is both compressively and laterally strong and because of its integrated nature is almost self-healing. Inspiration: A way to build a safer car bumper or highway guard rail. Durable and ultimately biodegradable packaging.
Sea Cucumbers	Contain dynamic elastics using the cross-linking of fibrous material allowing them to rapidly extend their length 400% Inspiration: easily stored travel items, packaging, travel cup…?
Sharks, anemones, and other marine creatures	Sharks heal from nasty wounds rapidly and are not known to get cancers as we do. Marine creatures, which live surrounded by pathogens in the sea, are full of novel defenses. Inspiration: New antibiotics, fungicides, a cure for cancer?

Slug mucous	This natural lubricant can absorb up to 1500 times its weight in water. Inspiration: flood control, clean up of spills.
Snake Fangs	Able to penetrate skin and inject material into the blood stream. Inspiration: The engineering inspiration for the hypodermic needle
Sphinx moth	Ability to detect tiny amounts of scents and navigate accordingly. Inspiration: Military studying these abilities which could be applied be to reconnaissance or detect pollutants or small amounts of TNT from leaking mines
Sponges	The spiracles of sponges have fiber optic abilities, but more flexible and tougher. Inspiration: non-toxic hardier light and information transfer
Tuna	Inspiration: “Robo-tuna: A new seagoing vehicle that is very efficient.” (biomimicry.org)
Venomous snakes	Assemble noxious chemicals in tiny amounts right when and where they are needed. Inspiration: manufacture necessary chemicals at the assembly line, so they do not need to be store or ship in dangerous quantities.
Vulture wings	It is aerodynamically designed to allow for lift, gliding and changing of direction and altitude. Inspiration: Wright brothers learned a lot about airplane design from birds.
Whale Blubber	Flotation, insulation, compact food reserve, and elasticity and recoil saves 20% of effort on each stroke for locomotion. Inspiration: Multi-use substances like blubber increase efficiency on multiple levels at once:
Whale tubicles	Those bumps on the fins of whales actually improve hydrodynamics. Inspiration: Tried on airplane wings increased fuel efficiency by 32%

Woodpecker	Scientists are studying the design of the skull of woodpeckers to see how they withstand such impact force. Inspiration: Applied to helmets, car safety, and maybe even the boxers will take a lesson?

* Indicate that it is a reference used in compiling the appendix

APPENDIX B: Available Curriculum Resources

Article with discussion guide: Janine Benyus: Biomimicry

An inviting five page article gives an overview of biomimicry that can be read individually or as a class and then discussed. PDF file is available at http://www.bioneers.org/programs/youth_initiative/pdf/benyus.pdf

Audio or Video tapes:

Janine speaking at the Bioneers Conference: available at www.bioneers.org

Two part series on Biomimicry from David Susuki's "Nature of Things". Can be shown as a whole or broken into sections according to topic.

Topics covered	**Unit overlap**
Part 1: Farming like a prairie	Agriculture Soils Botany
How does nature get energy: photosynthesis	Energy Photosynthesis
Companies taking Biomimicry to Heart	Economics

Industrial processes and waste Making recyclable plastics from waste CO_2	Chemistry Waste Management Biogeochemical cycles
Part 2: Mussels: Adhesive and Bissell Threads	Proteins/ Chemistry Science and/in Business
Abalone: the fracture resistant ceramic	Technology and medicine
Historical and philosophical commentary of industrial era	Sustainability Global world views

The Canadian Broadcast system maintains an interactive website with video clips at www.cbc.ca/natureofthings/show_biomimicry.html

Copies of the program can be purchased from Bullfrog Films at www.bullfrogfilms.com

Updated information can also be found at: www.biomimicry.org and www.biomimicry.info

REFERENCES

*Ackerman, R. A. (2000, 01/03). Futuristic materials inspired by biological counterparts. *Signal*, *54*(7), 37, 5. Retrieved from ProQuest Database February 3, 2005.

Ambrant (Photographer) Golden Orb spider. *Australia is amazing*. Retrieved March 26, 2005 from http://members.tripod.com/whimsicalwallaby/mission_beach.htm

*Anon. (2002, 01/03). Natural designs. *Environment* (Washington), *44*, 4. Retrieved from ProQuest Database February 3, 2005.

*Asia Intelligence Wire. (February 11. 1999). *The Hindu*. Chennai, India. 1. Retrieved on Febuary 3, 2005 from ProQuest Database.

*Ausubel, K. (Eds.) (2004). *Ecological medicine*. San Francisco: Sierra Club Books.

*Ausubel, K. (Eds.) (2005). *Nature's operating instructions*. San Francisco: Sierra Club Books.

*Ausubel, K. (Eds.) (1997). *Restoring the earth: Visionary solutions from the Bio-neers*. H.J. Kramer.

*Autumn, K., & Peattie. (2002). Mechanisms of Adhesion in Geckos. Integrated *Comparative Biology*, *42*(6), 1081-1090. Retrieved from WilsonWeb Database February 3, 2005.

Baumeister, D. (2004, May). Database project. *Biomimicry Guild Newsletter*. The Biomimicry Guild. *2*(2). 5. Retrieved February 22, 2005, from http://www.thinkcycle.org/tc-space/tspace?tspace_id=49344

*Ben-Ari, E. (2002, October). Geckos yield their sticky secret. *BioScience*, *52*(10), 960.

Benetti, B. &. d. C., L.M. (2002). Difficulties the science school teacher faces to implement environmental education. *In International Organization for Science and Technology*. Brazil.

*Benyus, J. (2001, July). Along came a spider. *Sierra*. *86*(4), 46, 2p,2c. Retrieved January 29, 2005 from http://www.sierraclub.org/sierra/200107/benyus.asp

*Benyus, J. (2002). *Biomimicry*. USA: Perennial.

*Benyus, J. (n.d.) *Biomimicry explained: A conversation with Janine Benyus*. Biomimicry Guild. Retrieved March 23, 2005 from www.biomimicry.net/faq_text.html

*Benyus, J. (2004). Voices of the Bioneers 2000: Janine Benyus: Biomimicry. *Bioneers Action Kit*. Collective Heritage Institute. 1-5. Retrieved February 25, 2005 from http://www.bioneers.org/programs/youth_initiative/pdf/benyus.pdf

*Benyus, J., & Baumeister. (2002). Packaging tips from the porcupine fish- and other wild packages. *Whole Earth*, Winter.

Biomimicry Guild. (n.d.). *Biomimicry*. Retrieved March, 2 2005, from www.biomimicry.org.

*Biomimicry Guild. (n.d.). *Materials*. Retrieved January 22, 2005, from www.biomimicry.org.

*Biomimicry Guild. (n.d.). *Processes*. Retrieved January 22, 2005, from www.biomimicry.org.

Bragdon, C. (2005, March). Biomimicry Guild Update. *Biomimicry Guild Newsletter*. The Biomimicry Guild. Vol. 3:1, pp. 1-2). Retrieved March 26, 2005, from http://www.thinkcycle.org/tc-filesystem/download/biomimicry_for_sustainable_innovation/thinkspace:_biomimicry_newsletter/resource___march_2005_newsletter__issue_3_1_/Biomimicry%20Newsletter%20v3.1.pdf?version_id=55111

*Buckminster Fuller Institute. (2001). *Biomimicry*. Retrieved 29 January 2005, from www.bfi.org/spring01/biomimicry.htm.

Bogo, J. (1999, November). Sustainability 101. *E: Environmental Magazine*, 10(6), 36.

Capra, F. (1996). The Web of life. New York: Double Day. Retrieved from ProQuest Database February 10, 2005.

Center for Ecoliteracy. . Retrieved 20 February 2005, from Center for Ecoliteracy.

*Chennai. (1999, 11 February). How do penguins survive and breed regularly in Antarctica despite the chill? *The Hindu* (India), sec. The Question Corner, p. 1.

*Collyer, Edwin. (October 25, 2001). Blueprints borrowed from nature's book: BIOMIMETICS: Living organisms have evolved ingenious solutions to complex engineering problems. Now scientists are trying to uncover their secrets- and outdo them. *Financial Times*. London, UK. p17.

*Copying what comes naturally. (1993, 08/03). Time (New York), 141, 58, 2. Retrieved from PeoQuest Database February 3, 2005.

Coyle, K. (2004, May). *Understanding environmental literacy in America*. Retrieved 09/03/2005, from http://www.neetf.org/roper/ELR.pdf.

*Dickinson, M.H. (1999). Bionics: Biological insight into mechanical design. From the Academy. 96(25) 14208-14209. Retrieved from Proceedings of the National Academy of Sciences of the United States of America (PNAS) on March 25, 2005 from http:www.pnas.org/cgi/content/full/96/25/14208

Disinger, J. &. R., C.E. (1992). Environmental literacy. (Report No. EDO-SE-92-1) East Lansing, MI: National Center for Research on Teacher Learning. (ERIC Document Reproduction Service). Retrieved from EBSCOhost Database February 23, 2005.

Eddy, J. (2004, May). Curriculum Project. *Biomimicry Guild Newsletter*. The Biomimicry Guild. Vol. *2*(2), 4. Retrieved February 22, 2005, from http://www.thinkcycle.org/tc-space/tspace?tspace_id=49344

Eddy, J. (2005, March). Curriculum Project Update. *Biomimicry Guild Newsletter*. The Biomimicry Guild. *3*(1), 3-5. Retrieved March 26, 2005, from http://www.thinkcycle.org/tc-filesystem/download/biomimicry_for_sustainable_innovation/thinkspace:_biomimicry_newsletter/resource___march_2005_newsletter__issue_3_1_/Biomimicry%20Newsletter%20v3.1.pdf?version_id=55111

Ekbourg, M. (2003, Summer). How student teachers use scientific conceptions to discuss complex environmental issues. *Journal of Biological Education*, *37*(3), 126-132.

*Fast, E. (2002, 11 December). Natural Designs- spectrum- using concepts from nature in industrial design. *New York Times* (New York), sec. E F.

Feral, C. (1999). Connectedness and development-- a theory. *Annual Convention of National Association of School Psychologist.* New Orleans: Education Resources Information Center (ERIC).

*Forbes, P. (2003, 16/01). Eluding the enemy. *The Guardian* (Manchester, England), p. 11. Retrieved from ProQuest Database February 3, 2005.

*Fraser, J., Narayanan. (2002, 01/12). Biomimicry: What can water quality professionals learn from Mother Nature? *Water Environment & Technology*, *14*(12), 44, 4. Retrieved from PeoQuest Database February 3, 2005.

Gang, W. (2004, 29 March). Education vital to raise society's environmental awareness. *China Daily* (North America Ed.), New York, NY, 5.

Glenn, J. & Sward, M. (2000, September). *Environment-based Education: Creating high performance schools and students* (Executive Summary). Retrieved from http://www.neetf.org/.

Goodall, J. (1999). *Reason for hope*. New York: Soko Publications.

Harvard University Kennedy School of Government. (2005). Wetland wastewater treatment. Government Innovators Finalists. Retrieved March 27, 2005 from http://www.innovations.harvard.edu/awards.html?id=3478

*Harvey, F. (2004, 27/02). Inspiration form nature's grand designs. *Financial Times* (London, UK), 13. Retrieved February 3, 2005 from ProQuest Database .

Haury, D. L. (2002, July). *Teaching about ecosystems.* (Report No. EDO-SE-02-02, 4). East Lansing, MI: National Center for Research on Teacher Learning. (ERIC Document Reproduction Service). Retrieved February 23, 2005 from ERIC Database .

Haury, D. (1998, December*). Education for environmental sustainability*. (Report No.) East Lansing, MI: National Center for Research on Teacher Learning. (ERIC Document Reproduction Service), 4. Retrieved February 23, 2005 from ERIC Database .

Hawken, P. (1994). *The Ecology of commerce*. New York: Harper Collins.

*Hawken, P., Lovins, A., & & Lovins, H. (2000). *Natural Capitalism*. August, 2000 (First edition). Back Bay Books. Retrieved from Rocky Mountain Institute (rmi.org): http://www.natcap.org/.

Heimlich, J. L. (1992). *Promoting concern for the environmental*. (Report No. EDO-SE-92-2), 3. East Lansing, MI: National Center for Research on Teacher Learning. (ERIC Document Reproduction Service). Retrieved February 23, 2005 from ERIC Database.

Hewson, P. &. Hewson, M. (1988). An appropriate conception of teaching science. *Science Education,* 72(5), 597-614.

Hicks, D. (1998, May). Stories of Hope. *Environmental Education Research*, *4*(2), 165-177.

Jensen, D. (2002, March). Thinking Outside the Classroom. *The Sun*, 1-13. Retrieved from www.centerforecoliteracy.org.

*Lang, P. and Springbelt, D.(Producer). (2002). Biomimicry: Learning from nature. *The Nature of Things.* [Television Series]. Canadian Broadcasting System. Oley, PA: Reproduced by Bullfrog Films.

**The Land Institute*. (n.d.) Retrieved March 13, 2005, from www.landinstitute.org.

Lappe, F., & Lappe. (2002). *Hope's Edge.* New York: Putnam.

Leopold, A. (1966). *A Sand County almanac*. New York: Ballentine Books.

*Lerner, S. (Eds.) (1997). *Eco-pioneers*. Cambridge, MA: The MIT Press.

Lieberman, G., & Hoody L.L. (1998). *Closing the Achievement Gap: Using the environment as an integrating context for learning* (State Education and Environment Roundtable). Retrieved February 23, 2005 from http://www.seer.org/extras/execsum.pdf

*Lipkin, R. (1996, March 9). Artificial spider silk: scientists vie to synthesize precious strands of the golden orb-weaver. *Science News Magazine* online. Retrieved March 26, 2005 from http://www.sciencenews.org/pages/sn_edpik/ps_5.htm

*Manchester Center for Mesoscience and Nanotechnolgy (editor). (2003, May 30). *Spiderman becomes a reality at the University of Manchester*. The University of Manchester News Centre. Retrieved March 26, 2005 from http://news.man.ac.uk/1054290245/index_html

*McDonagh, S. (2003, 7 June). Gecko-inspired adhesive is superstrong. *Science News* (USA), 163: 23, 356. Retrieved from WilsonWeb Database February 23, 2005.

*McDonough, W. (2002, 26/08). New war on waste. *Time* (New York), *160*, A28. Retrieved from ProQuest Database February 3, 2005.

*McElroy, A. (as cited in Biomimicry Newsletter, March 2003.) Retrieved March 26, 2005 from http://www.thinkcycle.org/tc-filesystem/download/biomimicry_for_sustainable_innovation/thinkspace:_biomimicry_newsletter/resource___october_2003_newsletter__issue_1_1_/Guild%20Newsletter%20v1.1cc.pdf?version_id=49350

Miller, J. T. (2004). *Living in the environment*. United States: Brooks/Cole-Thompson Learning.

Munson, B.H. (1994) Ecological misconception. *Journal of Environmental Education. 25*(4), Retrieved February 22, 2005 from EBCSO database: Academic Search Premier.

Orr, D. (1994). *Earth in mind*. USA: Island Press.

The National Environmental Education and Training Foundation (NEETF) & Roper Starch. (2001). Lessons from the environment:. *In Roper Starch National Report Card*. Retrieved on January 20, 2005 from www.neetf.org/roper/roper2001-a.htm.

NEETF. (2002). *Environmental education and educational achievement: Promising programs and resources*. Retrieved from http://www.neetf.org/.

National Forum on Partnerships Supporting Education About the Environment. (1996). *A program for change: Education for sustainability*. Retrieved from www.gcrio.org/edu/pcsd/intro.html.

Neumann, C. (2004, May). Biomimicry and Architecture. *Biomimicry Guild Newsletter*. The Biomimicry Guild. *2*(2), 1-2). Retrieved February 22, 2005, from http://www.thinkcycle.org/tc-space/tspace?tspace_id=49344

*Phillipkoski, K. (2004, December 21). Weeding out bacteria. *TechnologyReview.com.* Retrieved March 26, 2005. http://www.technologyreview.com/articles/04/12/wo_philipkoski122104.asp

Poore, P. (1993, April/May). Envio education: Is it science, civics-- or propaganda. *Garbage, 5*, 26-31. Retrieved from FirstSearch Database February 23, 2005.

Powers, E. (2004, May). Biomimicry and Architecture: From Maho Bay to the Pacific Northwest. *Biomimicry Guild Newsletter*. The Biomimicry Guild. Vol. 2:2, pp. 2-3). Retrieved February 22, 2005, from http://www.thinkcycle.org/tc-space/tspace?tspace_id=49344

*Robbins J. (2001, 11/12). Engineers ask nature for design advice. *The New York Times* (New York, NY), sec. F, p. F.1. Retrieved from ProQuest Database February 3, 2005.

Roszak, T. *Ecopsychology: Eight principals*. Retrieved February 2, 2005, from http://ecopychology.athabascau.ca/Final/intro.htm.

Roszak, T., & Ajhar. (1993, May/April). Beyond the reality principal. *Sierra, 78*(2), 58, 6p, 2c. Retrieved February 25, 2005 from Academic Search Premier database.

*Sagan, D. (1997, 31/08). You can't beat mother nature. *New York Times Book Review*, p. 16. Retrieved from ProQuest Database February 3, 2005.

Sewall, L. (1999). *The Ecopsychology of perception*. New York: Penguin Putnam Inc.

Sobel, D. (1995, Nov-Dec 1995). Beyond Ecophobia. *Clearing*, 9, 16-20.

Sobel, D. (1997). Sense of place education for the elementary years. In *Coming home: Developing a sense of place in our communities and schools.* Retrieved March 10, 2005, from ERIC Document Reproduction Service).

*Spotts, P.N. (August, 19, 1997). Seashells yield tough secrets scientists tap them for hints on building stronger cars, tanks. *Christian Science Monitor*. 12. Retrieved from ProQuest Database February 3, 2005.

*Stealing inspiration ends up being in out nature. (2002, 12/06). *South China Morning Post* (Hong Kong), p. 9. Retrieved from ProQuest Database February 3, 2005.

*Stamets, P. (2005, February, 24). Earth’s natural Internet: Healing the planet with mushrooms. *BioInspire.* 1-4. Retrieved March 26, 2005, from http://www.thinkcycle.org/tc-filesystem/download/biomimicry_for_sustainable_innovation/thinkspace:_bioinspire_monthly_publication/resource___february_2004_newsletter__earth_s_natural_internet___healing_the_planet_with_mushrooms/BioInspire.24%2002.24.05.pdf?version_id=54858

*Stone, A. (1999, 07/10). Military enlisting specialists from nature. *USA Today* (McLean, VA), sec. News, p. 07.A. Retrieved from ProQuest Database February 3, 2005.

*Stroh, M. (2003). Chasing the wily gecko toe. *Popular Science* (USA), *263*(3), 39.

Tapia, I and Blochmann, G. (Eds.) (2000). Environmental education in Germany: Concepts, history, projects, visions. *Bildung und Wissensharft*. Inter Nationes: Bonn, Germany. 1-33. Retrieved from ERIC Database February 10, 2005.

*Valigra, L. (1999, July 22). You want strong- we've got strong! *Christian Science Monitor* (Boston, Mass), sec. Features, 13. Retrieved from ProQuest Database February 3, 2005.

*Virgano, D. (2003, August, 21). Sponge goes man-made fiber optics one better. *USA Today*. Tech section. The Associated Press. Retrieved March 26, 2005, from http://www.usatoday.com/tech/news/techinnovations/2003-08-20-sponge-fibers_x.htm

White, E.B. (1974). *Charolette’s web*. HarperTrophy. New York.

Wikipedia, the free encyclopedia. (2005, 14 March). Biomimicry. Retrieved 13, March, 2005, from http://en.wikipedia.org/wiki/Biomimicry."

Zimmermann, L. (1996, Spring). Knowledge, affect, and the Environment: 15 years of research (1979-1993). *Journal of Environmental Education*, *27*(3), 41-45. Retrieved from EBSCOhost Database February 23, 2005.