Biomimicry and Science: Applying Nature's Strategies

ecoRise
YOUTH INNOVATIONS

BIOMIMICRY INSTITUTE

Welcome!

Biomimicry and Science: Applying Nature's Strategies introduces students to eco-literacy and design innovation concepts through project-based learning methodologies and by emphasizing real-world applications. At a time when we need sustainable solutions to solve many pressing local and global challenges, researchers are finding that solutions to many of these problems already exist in nature. Biomimicry is the practice of looking to nature for strategies to solve human challenges. This course introduces students to biomimicry via numerous striking examples, with connections to core content in chemistry, physics, and biology.

The Program Includes:

✓ **Introduction to Biomimicry**—a lesson that can be used as a launching point in any classroom to orient students to the exciting practice of biomimicry

✓ **15 unique and engaging biomimicry-based science lessons**—five for each of three core areas: chemistry, physics, and biology

✓ **Biomimicry Design Challenge Module**, which consists of seven lessons that facilitate a long-term project centered around the topic of biomimicry for participation in the Biomimicry Institute's Biomimicry Global Design Challenge or a similar capstone project

✓ **Five beautiful and engaging posters**—designed to inspire and intrigue students to use biomimicry

✓ **Inspired by Nature Cards**—these cards can be used in many ways to help students understand function and strategy in nature and come up with nature-inspired solutions to a variety of problems.

✓ **Lessons with a range of teaching strategies**, such as presentations, videos, activities, assessments, technology integration, and community extensions

✓ **Standards alignment** to Common Core State Standards (CCSS), Next Generation Science Standards (NGSS), Cloud Education for Sustainability (EfS) Standards & Performance Indicators, and the Texas Essential Knowledge & Skills (TEKS)

Contents in Brief

Annotated Contents

Introduction to Biomimicry

Introduction to Biomimicry Lesson

This lesson introduces students to the concept of biomimicry. In the first session, students participate in a presentation that invites them to question where ideas come from and how our built world was imagined and constructed. Students discuss why designers are studying nature's solutions and identify some of nature's design achievements (such as energy efficiency, recycling, zero-waste systems, solar energy, etc.). Then they look at several examples of biomimicry and learn how some of nature's strategies have inspired solutions to current challenges. The session concludes with an inspiring and compelling video about Janine Benyus, a biologist and a prominent champion of the biomimicry concept. From this passionate leader, students learn the philosophy and core values of biomimicry. The video also includes several additional striking examples of biomimicry.

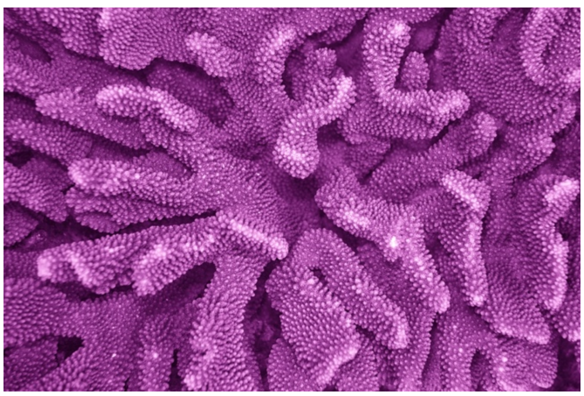
In the second session, students go outdoors to a natural space. First, they close their eyes and use their other senses to perceive the natural world around them. In this way, they reawaken their understanding of the natural world in which they live and also reflect on how animals are highly attuned to the environment around them. In the second outdoor exercise, students take turns handling natural objects while blindfolded in order to guess and describe what functions an object (or part of an object) serves in the natural world.

Chemistry and Biomimicry

LESSON 1:
Make It Stick!—Nature's Adhesives

In this lesson, students explore both human-made adhesives and adhesion strategies found in nature while learning about intermolecular forces and the chemical properties of adhesives. As they do so, they have an opportunity to experience their understanding of an important chemistry topic through the lens of biomimicry. They begin by viewing a presentation that describes the ways adhesives work, and then they consider a variety of natural adhesives. Students examine the odd and compelling strategy used by the gecko and explore the concept of van der Waals forces to investigate the advantages of structural adhesion over chemical adhesion. In the second session, students apply what they have learned about adhesives as they complete an adhesives lab. In the lab, students explore which human-made adhesives are most effective for various tasks and how they compare to adhesives found in nature. As a class, students then share their findings and reflect on how our current methods of adhesion could be improved upon by applying the principles of biomimicry.

LESSON 2:
Coral, Carbon, and Concrete



In this lesson, students explore the science behind an endangered ecological treasure: coral reefs. Students review the carbon cycle and examine how hard corals collect carbonate and calcium ions from seawater and use those materials to build calcium carbonate skeletons in which the soft coral polyps live. Students are then encouraged to note the differences between the natural calcification processes of hard corals and the processes humans use to make concrete. During a lab activity, students produce calcium carbonate from seawater and carbon dioxide (CO2) by mimicking one of the processes that corals use. Via this lab work and reflection, students consider what humans can learn from the process of coral formation and explore how biomimicry could help humans better regulate carbon emissions by learning to mimic natural processes. As students explore these concepts, they also learn important chemistry content, including how atoms form bonds, the behavior of solutions, and the predictive power of the periodic table.

Chemistry and Biomimicry, continued

LESSON 3:
Raspberry Solar

In this lesson, students consider how photosynthesis, the process that plants use to create energy, is similar to and different from the process used by human-designed photovoltaic (PV) systems. Students identify some of the harmful consequences of the human-designed process and ponder whether current solar technology is always as green as it seems. Then they investigate a specific type of PV cell that uses several common, organic elements that make it a more sustainable option. Students then apply their new knowledge and create a dye-sensitized solar cell that uses raspberries and other nontoxic materials. They put their solar cells to work and monitor how much energy their raspberry solar cells generate in different light settings. Finally, students reflect on how plants use "green" chemistry to harvest energy without consuming or producing toxic chemicals and how we might be able to use the concepts of biomimicry to build a better solar cell.

LESSON 4:
The Ultimate 3D Printer

In this lesson, students explore how biomimicry could shape a new revolution in product manufacturing: 3D printing. Biomimics are drawing attention to the drawbacks of the last manufacturing revolution—the industrial revolution—and how many of the methods and materials we have used to make things are not in harmony with natural processes. Students see that, as we are on the cusp of a new 3D printing revolution, researchers are engaged in finding ways to take cues from nature, studying the materials and processes nature uses to build structures, with the goal of finding ways to use similar methods and materials in 3D printing to truly revolutionize manufacturing as we know it and create a more sustainable future. After considering the ideas of biomimics, students take up the challenge and work in teams to come up with an idea for a product that could be created with a 3D printer using natural polymers. Students then share their ideas with the class and help each other refine and improve their innovations to make them as useful and sustainable as possible.

Chemistry and Biomimicry, continued

LESSON 5:
The African Midge and Vaccine Stabilization

In this lesson, students explore the topic of cryptobiosis, which is a physiological state in which an organism's metabolic activity slows to a reversible standstill. Some organisms use this strategy to survive extreme conditions, such as a shortage of water, low or high temperatures, extremely salty water, or a lack of oxygen. Specifically, students analyze a scientific article to discover how the African midge, a tiny fly from northern Nigeria, can survive a wide range of extreme conditions including major variations in temperature, extreme drought, and airless vacuums such as outer space. They focus on the process of anhydrobiosis, which the midge uses to survive without water for long stretches of time. Students conduct a lab activity to investigate two important concepts: stabilization and solubility. They explore how a suspension could be stabilized and investigate factors that affect solubility. Then they apply what they've learned to an analysis of how the principles of anhydrobiosis might be used to create vaccines that can be effectively transported to people in remote corners of the world.

Physics and Biomimicry

LESSON 1:
Elastic Energy and the Mantis Shrimp

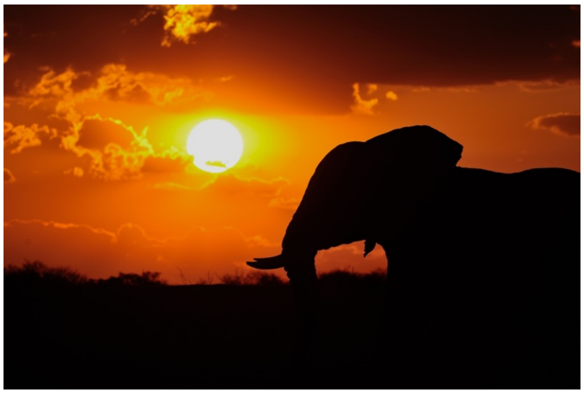
In this lesson, students build upon their previous knowledge of potential and kinetic energy by exploring the concept of elastic energy storage via a case study of the mantis shrimp. One of nature's most unusual and extraordinary creatures, the mantis shrimp, possesses the most powerful strike in the animal kingdom. In the first session, students investigate the structure of a mantis shrimp's striking appendage. A spring-and-latch mechanism, made up of several parts of the animal's exoskeleton, includes an immensely powerful spring that stores potential energy in the form of elastic energy and a latch that allows the mantis shrimp to suddenly release its appendage with immense kinetic energy. In the second session, students complete a lab to test how a vinyl toy popper can store tremendous potential energy, and they work with several formulae to determine the potential energy and kinetic energy of the popper. Finally, students reflect on their lab work and ask themselves how biomimicry and what we observe from the mantis shrimp might increase our ability to store elastic energy and harness it for human use.

LESSON 2:
Built for Brilliance: Structural Color

This lesson begins with students recalling what they know about light. They then acquire a clearer understanding of how light behaves by recreating the classic double-slit experiment. A video gives students perspective on how difficult the concept of light can be to understand and how the double-slit experiment helps clarify its fascinating properties. In the second session, students view a presentation that covers the concepts of light, color, electromagnetic waves, and wave interference. They consider how pigments create color versus how structures can create color and iridescence. Through an investigation of the blue morpho butterfly and other organisms, students learn how nature can use structures to create enduring and impressive colors. They then look at an example of one company that is using structure to create color in materials, and they brainstorm their own ideas about how structural color might be used in human creations in the future.

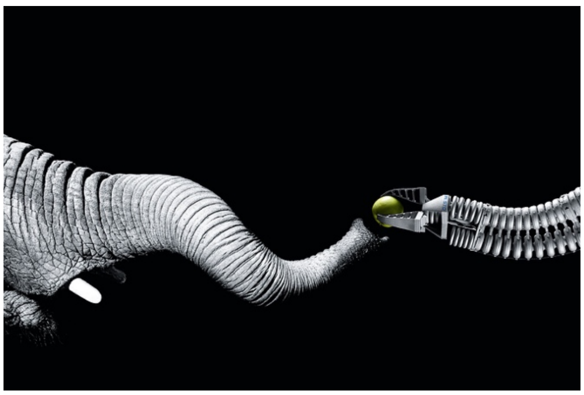
Physics and Biomimicry, continued

LESSON 3:
Elephant Hot Spots



In this lesson, students learn how African elephants have thermal windows, or "hot spots," that help them thermoregulate by radiating excess thermal energy. Students read an article and study thermal images to explore how a complex network of tiny blood vessels help an elephant maintain homeostasis in a hot climate. Students then further process what they've learned by attempting to simulate an elephant's hot spot using lab materials. Finally, students think critically about how humans could apply what we've learned about elephant hot spots to solve human challenges and they brainstorm some of their own ideas.

LESSON 4:
The Nature of Robots



In this lesson, students learn that, contrary to many examples from movies and pop culture, most robots do not look like humans. They see how, rather than simply trying to make exact replicas of organisms, many modern roboticists observe strategies and structures that have evolved in nature and use them as a starting point for their own designs. Students explore several specific examples of bio-inspired robots and consider how studying the form and function of organisms has helped roboticists address human challenges. Then they apply the biomimicry design process to design their own bio-inspired robot that will solve a specific personal or societal challenge.

LESSON 5:
The Amazing Pomelo Fruit

In this lesson, students learn how the specialized structure of a pomelo fruit peel provides it with shock absorption properties that protect the massive fruit when it free falls from a soaring tree branch. Students explore the factors that cause an object to have high levels of potential energy as well as structural characteristics that enable an object to dissipate large amounts of energy on impact. Next, students apply what they've learned in an egg-drop challenge. This twist on the traditional egg-drop challenge pushes students to design an egg "peel" using a variety of lightweight materials that are combined in such a way as to model the gradual transition in density that is characteristic of a pomelo fruit peel. Lastly, students explore real-world applications of materials that have remarkable shock-absorption properties.

Biology and Biomimicry

LESSON 1:
Catching the Fog

In this lesson, students learn about adaptations that allow Namib Desert beetles to harvest water vapor from the air in order to survive in the water-scarce desert. They explore how physical design and behavioral adaptations allow these beetles to “catch the fog.” Then they consider several examples of human innovations that incorporate some of the beetles’ strategies to solve challenges human face. In the second session, students apply what they've learned by designing and building a working prototype of a dew catcher.

LESSON 2:
Swarm Intelligence and Smart Systems

In this lesson, students learn about how simple organisms can solve complex problems via a collective intelligence known as swarm intelligence. The lesson begins with an active simulation in which students see first-hand what can happen when a group follows simple rules. They then explore the concept of swarm intelligence in detail through examples of collective group behavior in ants, starlings, and honeybees. Next, they consider what scientists have discovered about coordinated systems in nature, and they look at how key principles of swarm intelligence can be applied to smart devices and in computing to solve complex human challenges, such as increasing energy efficiency in commercial buildings and using robots for rescue missions.

Biology and Biomimicry, continued

LESSON 3: Industry and Ecology: A Natural Fit

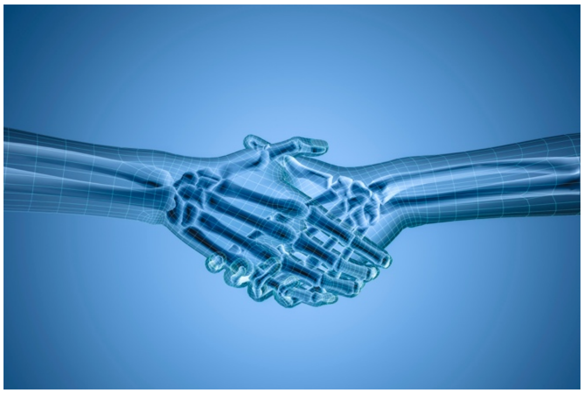
In this lesson, students learn about the complex system of checks and balances that make the North American Prairie ecosystem one of the most biodiverse and resilient systems in the world. The interdependencies of the prairie system and its ability to survive and thrive in the face of environmental disturbances such as fire and drought, make it a model of environmental and economic sustainability. Students apply this model to industry, investigating the concept of industrial ecology and how it applies to heavy polluters such as coal-fired power plants. They study the Kalundborg Industrial Ecosystem, which serves as a prime example of industrial ecology in action. Then students tour their school and conduct research to determine how aspects of the North American Prairie ecosystem and Kalundborg could be applied to their own school community. They identify how waste byproducts from one process in their campus system could be used as a resource or input in another process, thus increasing the environmental and economic sustainability of the school.

LESSON 4: Pond Killers and Dead Zones

In this lesson, students learn about ecosystem balance and the nitrogen cycle. They explore how modern human activities can disrupt natural systems and cycles, such as when fertilizer from industrial agriculture runs off into streams, rivers, and lakes. Students learn about algal blooms and become familiar with terms like eutrophication and hypoxia. They conclude Session 1 by setting up an algae bioreactor and fertilizing it with one of several nutrient sources to compare how nutrients in organic and synthetic forms lead to different outcomes. In Session 2, students discuss how biomimicry can be applied at different scales, such as at the level of structures, processes, or entire systems. They investigate one system design for cleaning waterways, one which mimics the natural filtration of a wetland. Finally, in Session 3, students revisit the algae samples they set up in Session 1 and examine the impact that various nutrients have on algae populations. They consider what humans can learn from the way nature balances nutrients so we can avoid befouling our waterways in the first place and restore balance to damaged systems.

Biology and Biomimicry, continued

LESSON 5: Inspirational Bones



In this lesson, students learn that bones are made of soft and hard materials with empty spaces interspersed to provide strength and structure for a body while minimizing weight. Students explore the various functions that bones serve, and examine how differing structures within different bones suit specific functions. Then students key into several properties of bones that are of interest to innovative problem-solvers. They learn how these properties can be applied to solve structural engineering problems, such as building more efficient cars, furniture, or buildings. Finally, they are challenged to apply what they've learned by working with a partner to build a strong, lightweight structure that can support a heavy weight.

Biomimicry Design Challenge

LESSON 1:
Design Thinking and Biomimicry

This lesson introduces students to a design thinking process that can help them apply principles of biomimicry to address critical real-world problems related to important social or environmental issues. It sets the stage for a biomimicry design capstone project and/or participation in the Biomimicry Global Design Challenge. In this first lesson, students explore the concept of design thinking and how it can be helpful in inspiring innovations. They also learn a design process that consists of five steps and integrates principles of biomimicry. Then they form teams and begin thinking about a design problem they would like to solve using biomimicry.

LESSON 2:
Identifying the Design Challenge

This lesson introduces students to the first step of a biomimicry design thinking process: how to identify (or define) a design problem and its associated criteria and constraints. Students begin with a mind-mapping activity to help them explore various aspects of the biomimicry design challenge and to identify a manageable design problem their team can address. Teams work collaboratively to select an aspect of the design challenge to focus on. They summarize what they've decided by formulating a "design question" that identifies the context, constraints, and ultimate goal of their design.

Biomimicry Design Challenge, continued

LESSON 3:
Exploring Nature's Solutions

This three-part lesson begins with an outdoor experience in which students practice observing nature with a curious mind and begin speculating about the functions behind what they observe. In the second session, students view a presentation that introduces a method for translating design questions into terminology that can be used to search biology for applicable strategies. Then they participate in a game-show-style activity to reinforce their understanding. The session concludes with a homework assignment in which students work in their teams to apply what they have learned to translate their design question from the previous lesson into a "How does nature…" research question. In the third session, students learn about credible sources and methods for finding biological strategy information. Then they work in their teams to develop a research plan to investigate their "How does nature…" questions and begin finding biological models.

LESSON 4:
Exploring Natures Patterns

In this lesson, students learn about patterns, the different ways patterns appear in nature, and how being observant of patterns can support biomimetic design. The lesson begins with a presentation that introduces patterns in nature at three scales that are relevant to biomimicry: visual/form patterns, process patterns, and system-level patterns. Afterward, students practice identifying patterns in a small-group activity and then apply what they have learned in their ongoing design challenge research, which was introduced in the previous lesson.

Biomimicry Design Challenge, continued

LESSON 5: Creating Nature-Inspired Ideas

In this three-part lesson, students begin to generate design ideas from the biological strategies and patterns they discovered in previous lessons. In the first session, they learn how to translate biological strategies from their research into biomimetic design strategies that can be applied to a design problem. In the next session, they participate in a biomimicry brainstorming activity to generate many diverse design ideas for applying those design strategies. In the final session, they assess those ideas more closely for relevance and feasibility and select the strongest idea to carry forward in the design process.

LESSON 6: Refining the Design

In this lesson, students participate in a peer review and other activities that help them evaluate and improve the design idea they selected in the previous lesson. In the first session, they complete an analysis exercise that leads them to uncover the "pains" and "gains" of their current design idea and identify and record the next steps for refining the design. A homework assignment following the first session prepares students to participate in the second session, in which they present their work in progress to their peers for constructive feedback, which they then incorporate into their final design solution.

LESSON 7: Sharing Design Solutions

This lesson provides a framework to help students finalize and share the results of their Biomimicry Challenge project. Students develop a concise description to promote their design concept, plan and record a video pitch, and create a visual presentation to detail their design solution. If applicable, students also prepare their final design proposals to enter the Biomimicry Global Design Challenge (BGDC) competition.

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by EcoRise Youth Innovations and Biomimicry Institute

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EcoRise Youth Innovations
Gina La Motte, Executive Director
Jenji Henson, Chief of Curriculum Development
Christina Mirando, Chief Designer
Laura Fuller, Curriculum and Design Assistant; Permissions
Abby Randall, Writer and Programming Consultant
Elizabeth Stephens, Writer
Kayte VanScoy, Writer
Michael Neibergall, Copyeditor
Suzanne Noguere, Copyeditor
Angelica Chacon, Correlations

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