"Look deep into Nature and then you will understand everything better."

Albert Einstein

The Designed World – Module 2
Engineering, Naturally

If you want to learn about some of the best engineered solutions – look in your own backyard. Nature is the ultimate problem-solver. If you want a sustainable solution, following Nature's lead is usually the best place to start. *Biomimicry* , the practice of observing and emulating nature when designing and engineering solutions, provides a terrific platform for incorporating engineering design projects into life science, environmental science, and biology curricula. In Module 1 of this three-part series, students looked at the designed world we have created and began to develop an understanding of the ability of engineering and technology to solve our problems. In this module, student designers are asked to look outside as they identify how Nature solves the challenges inherent in the process of living on this planet.

Engineering is all about problem-solving and finding innovative solutions to meet human needs and improve our lives. Good engineering demands knowledge and strategic use of structures and materials; it requires the ability to understand systems impacts, feedback loops, and unintended consequences. Nature inherently operates on those principles, adapting or modifying slowly to take a long-term, sustainable approach to optimization. And nature has been successful for 3.8 billion years. There is clearly much we can learn by modeling our approach to design on Nature's processes. As Janine Benyus, founder of the Biomimicry Institute and a long-time champion of biomimicry, says, "*The more our world functions like the natural world, the more likely we are to endure on this home that is ours, but not ours alone."*

The way structures, processes, and systems in Nature are engineered follows the same engineering design principles mapped out in the NGSS and other standards. Different parameters and a longer timeframe exist in the natural world. The table below compares Nature's approach to sustainable design over the past 3.8 billion years to the process we have employed to create the modern industrial world in less than 300 years.

Engineering Design Process	Nature's Approach	Human Approach
Define the Problem	Sustain life	Make life "better"
Identify Criteria	Non-toxic, low temperature, recyclable, renewable	Bigger, stronger, cheaper, safer, appeal to target audience
Determine Constraints	Only locally available resources	Least expensive resources, limited time
Testing and Modification	Slowly over time, prolonged use, extensive population	Rapid, often limited scenarios, small pilot samples
Optimization	Sustain life with least negative impacts; positive impacts outweigh negative consequences	Bigger, better, faster, more profitable; often maximize not optimize

Clearly, as we face the challenges of limited resources, increasing population, and relatively rapid changes in our environment, there is much that we can learn by studying the structures, behaviors and processes, and systems that Nature has engineered. Using resources locally, minimizing waste, valuing structure over quantity, and avoiding the use of toxic compounds will help to ensure a better world for all.

In terms of the curricular projects we design, we think of biomimicry in terms of increasing levels of complexity that fit well into increasing grade level skills and learning progressions. Our focus at lower grade levels is on patterns and common structures. At the middle school level, we look more at the efficiencies and guiding principles behind structures and an understanding of behaviors and natural processes such as photosynthesis, cellular respiration, and heat transfer. For students who are older, modeling based on natural ecosystems provides a comprehensive approach to systems thinking, circular economies, and renewable design.

During this time when students are at home, the time spent doing some research and scientific investigation outside is a welcome change of pace. The timing is good - it is often easier to observe the structures and patterns in nature as animals and plants re-emerge and reappear after the winter. The following activities are meant to guide "engineers" as they do some background research about sustainable practices and solutions. Our final module (available in early May) will ask students to apply ideas from both this module and Module 1 to specific design challenges in order to focus on sustainable solutions.

Engineers have always worked to solve problems, but our future lies in our ability to solve those problems sustainably and with less negative impacts. Looking at how Nature has engineered for 3.8

billion years can inspire and empower the engineers in your classes. Check out the list at the end of this document to get an idea of how we have already turned to Nature for inspiration as we engineer better solutions.

The activities and resources suggested in the following table have been designed for different grade levels, but many can be adapted for a range of ages. Worksheets and resources for ProjectEngin materials can be found at the end of this document; activities and information from other sources can be found by following the link given.

Inspiration from Nature Activities

Activity/ Resource	Grade Level	Website/Location	Summary
Hiding in Plain Sight	K-2	Document attached	Examine some of the patterns in butterflies
Patterns and Shapes	K-4	Worksheet https://docs.google.com/file/d/0B-AhOnNzdyA5dllwWnM1NjRZZ0E/edit Background Information https://www.playfullearning.net/resource/patterns-in-nature-scavenger-hunt-printable/ Great photos and slides about patterns in Nature https://www.thesmartteacher.com/exchange/resource/333/Abstract_Patterns_in_Nature	Uses pictures of various patterns and the idea of a scavenger hunt
	All	Terrific photographs of camouflage in Nature – gallery of 400+ slides	
		Pictures and video about Liu Bolin – artist who makes himself "invisible" https://www.smithsonianmag.com/videos/category/arts-culture/how-does-liu-bolin-make-himself-invisible/ https://communityoflights.com/index.php?option=com_content&view=article&id=411:liu-bolin-the-master-of-camouflage&catid=64:photography&Itemid=234 https://www.designboom.com/art/liu-bolin-a-colorful-world-klein-sun-gallery/	Students love learning about this artist and trying to find him in his photographs

Structures and Patterns	3-5	Teach Engineering Activity – Compare and Contrast Chart https://www.thesmartteacher.com/exchange/resource/333/Abstract_Patterns_in_Nature	Teacher doc that highlights patterns in Nature
		Why Nature Loves Hexagons (PBS video) TED Ed lesson – Why Do Honeybees Love Hexagons?	Good for a wide range of ages
	6-12	Fractals in Nature Patterns in Nature – great summary of symmetry, fractals, etc. 3 Patterns in Nature - from the Franklin Institute	Terrific connections to geometry and art
Inspiration for Structures	4-12	Animal Architects from National Geographic Buildings Inspired by Nature - BBC TED Talk Using Nature's Genius in Architecture	Great examples of how we can build better
Working Together – It Starts with a Process	6-9	30 Animals That Have Made Us Smarter – worksheet attached	Video and podcasts from the BBC that highlight solutions from Nature.
Systems and Circles	8-12	• Inspiration from Nature WS (attached); use Ask Nature website • Innovators Who use a Circular Approach https://www.greenbiz.com/article/just-add-nature-7-biomimicry-entrepreneurs-debut-circularity-19 • Bio-Inspired Solutions https://innovation.biomimicry.org/launchpad/ • Biomimicry Institute Nature Observation Guide • Biomimicry Systems Explorer Worksheet	Investigate processes and systems that Nature uses to solve problems

The resources above are good ones to start with as you encourage the engineers and designers in your classes to look outside for inspiration. In addition to any worksheets listed as attached, other resources that we have found helpful follow along with a list of bio-inspired technologies. Think of this module as being student-led research. The next module in this series will focus on sustainable solutions and students will get a chance to apply some of the inspiration that have obtained as they researched Nature's approach to solving problems and meeting challenge.

Some additional biomimicry resources that we use at ProjectEngin:

General:

The Biomimicry Institute

Ask Nature

Inhabitat

Green Biz

30 Days of Biomimicry from the Biomimicry Institute

https://biomimicry.org/30days/

Best introductory videos/TED Talks

Featuring Janine Benyus of the Biomimicry Institute https://youtu.be/sf4oW8OtaPY

PBS Newshour video https://youtu.be/neUKzwYDB_c

Janine Benyus (Biomimicry Institute) TED Talks

Surprising Lessons from Nature"s Engineers

Biomimicry in Action

Education resources from the Center for Learning with Nature

Shape of Life – Animals as Engineers (Grades 7-12); lesson plan and videos

https://www.shapeoflife.org/lesson-plan/sol/natures-innovations-animals-engineers

Great video about the color blue in Nature (Grades 8-12) https://youtu.be/3g246c6Bv58

Spider Silk - TED Talk
https://www.ted.com/talks/cheryl_hayashi_the_magnificence_of_spider_silk?language=en#t-3634

Cooper-Hewitt Lesson Plan – Architecture Inspired by Nature (Grades 6-9)

https://dx.cooperhewitt.org/lessonplan/biomimicry-nature-architecture-of-the-future/

Great examples of bio-inspired inventions

https://theleonardo.org/10-ways-nature-inspires-modern-technology

K-2 Lessons

Generation Genius – video, lesson plans, grade appropriate reading materials, teacher guide

https://www.generationgenius.com/videolessons/inspired-by-nature-biomimicry-video-for-kids/

MS/HS Lesson Plans

Try Engineering – lesson plans and student worksheets

https://tryengineering.org/teacher/biomimicry-engineering/

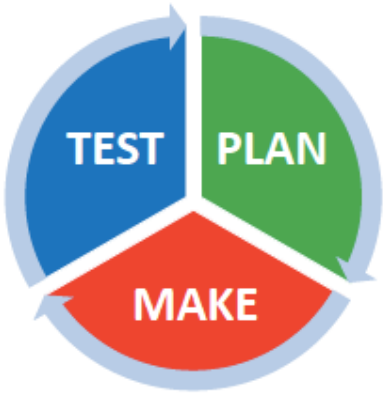
Examples of biomimetic or bio-inspired design:

- *Airplanes* modeled after birds (wing and body shapes, falcon beak)
- *Morphing airplane wings* that change shape according to the speed and length of a flight, inspired by birds that have differently shaped wings depending on how fast they fly
- Fish-inspired scales that easily slide over each other to enable the *morphing airplane wings*
- *Boat hulls* designed after the shapes of fish
- *Torpedoes* that swim like tuna
- *Submarine and boat hull material* that imitates dolphin and shark skin membranes
- *Radar and sonar navigation technology* and medical imaging inspired by the echo-location abilities of bats
- *Swimsuit, triathlon and bobsled clothing fabric* made with woven ribbing and texture to reduce drag while maintaining movement, mimics shark's skin
- *Adhesives* for microelectronics and space applications inspired by the powerful adhesion abilities of geckos and lizards
- *Water filters* designed like animal cell membranes to let certain things pass through while others are kept out
- *Running shoes* with technology learned from studying the mechanics of animal feet
- *Super strong and waterproof silk fibers* made without toxic chemicals by spiders
- *Ceramics and windshields* modeled after the mother of pearl material made by abalone mussels
- *High-speed trains* modeled on the kingfisher
- *Underwater glue* for slippery surfaces, as made by mussels
- *Anti-reflective, anti-glare film* used for flat panel displays, touch screens, lamps, and phone lenses that replicates the nano-structures found in the eyes of night flying moths
- A better *ice pick for mountain climbers* designed after the woodpecker.
- *Glow sticks* made with light-up chemicals, just like fireflies
- Very *efficient pumps and exhaust fans* applying the spiraling geometric pattern found in nautilus seashells, galaxies and whirlpools
- *Hook and loop material (Velcro©)* inspired by cockleburs
- *Solar cells* inspired by plant leaves (photosynthesis, capturing energy from sunlight)
- *A wind-driven planetary rover design* that maximize drag, learned from the tumbleweed
- *Self-cleaning exterior paint, tiles, window glass and umbrella fabric* inspired by the slick leaves of the lotus flower plant and its natural ability to wash away dirt particles in the rain
- *Reduced-drag propeller designs* inspired by the spiral shape of kelp, which moves with the current rather than fight it, so much less energy is required to move water or a ship
- *Water filter system* that acts like a marsh

Hiding in Plain Sight

Literacy Connections Optional:

The books, *The Very Hungry Caterpillar* by Eric Carle, and *A Butterfly Is Patient* by Dianna Aston, are great literacy tie-ins to the activities to follow.



Background

Students will use a modified engineering design process, in using the natural surroundings to camouflage a butterfly in their classroom. It is important for students to understand that it is Nature engineering and continually making modifications that is responsible for the camouflage.

Grades: K-2 **Time:** 60 minutes

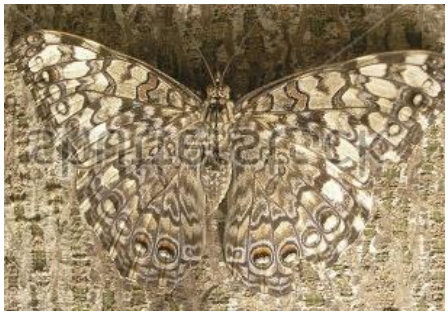
Materials

- *The Very Hungry Caterpillar* by Eric Carle
- *A Butterfly Is Patient* by Dianna Aston
- Butterfly Shape handout
- Scissors
- Coloring crayons, markers, or pencils (for "camouflaging" butterfly)

Overall Plan

Introduction

- What do engineers do? (build things, make things)
- Can you name some creatures that act like engineers? (ants, birds and their nest, beavers and their dam, butterfly's camouflage etc.)
- How do people use camouflage? (Invisible Man photos http://www.cbsnews.com/pictures/chinese-artist-hides-in-plain-sight/7/
- What kind of patterns are helpful in camouflaging the person and butterfly?



Nature Inspired Engineering Process

- **PLAN:** Engineers are often inspired by nature (airplanes and birds, sleeping bags and fur, and camouflage, etc.) Display or show images of butterflies and their camouflage. Engineers need to **PLAN** how they want to use nature in their design.
- Then they **MAKE**
- What do you think they do next? (**TEST** it to make sure it works)

So we will be Engineers and will Plan, Make, and Test!!

Activity

We are going to design camouflage for a butterfly using the natural environment of our classroom. To do this you must:

1. Use At Least Two shapes (circle, square, rectangle, etc.)
2. Use At Least Two different colors
3. Then place the butterfly in your planned location in the classroom (posters, walls, etc.) It CANNOT be placed behind anything.

Divide students into groups of 2 to 3 and hand out **PLAN**, **MAKE**, **TEST** worksheets (one for each student even if they are working in groups).

- Before you make your butterfly camouflage, you need to make a drawing or a **PLAN**. Students will identify a spot in the classroom, that represents their butterfly "environment".
- Draw a picture of the shapes you will use in your design in the box that says PLAN
- Get the colors that you will be using. Color in your shapes with the colors you will be using.
- Then you can **MAKE**, but no testing until your teacher says you can
- Draw a picture of the butterfly you made in the box that says **MAKE**

TESTING:

1. Have students tape their butterfly designs to the area of the classroom that they chose, one by one, while the other students have their heads down.
2. Once they are all posted to the classroom, students will turn into "butterfly hunter" birds and will "eat" a butterfly they find. Give students 3-5 minutes to do this.
3. After you "test", draw or write about what happened in the **TEST** box. What can you do to improve your design?
4. Identify any butterflies that were not found initially, and discuss why they were not.
5. Students will draw a picture of a NEW **PLAN** to improve their old design. In the engineering world we call this Modifying a design. Nature does this with camouflage through constant modifications of patterns due to environment.
6. Get any additional materials or colors you need and **MAKE** your new design.
7. Have students do a gallery walk, looking at how the designs have modified or "adapted".
8. **Relate the NEW design and those not found to how butterflies that have a better genetic adaptation, allows them to blend in better, and they can live longer and pass those adapted genes on to more offspring.**

Reflection:

Who made the best camouflage design?
Which was your favorite (other than your own)?
How did you modify or change your design after the first plan?

Extension and Modifications:

- For a formative assessment, have students draw, write, or using verbal ques, discuss their understanding of patterns and symmetry relating to camouflage and adaptation.
- As a modification, have students hide their butterflies and then several days later have students find them.

30 Animals That Have Made Us Smarter

Name: _____

Animals need to solve some of the same problems that we have. They need to get food, stay warm, find a place to live, and stay safe and healthy. Engineers have learned a lot by copying Nature. This is called *biomimicry* or *bio-inspired engineering*. Biomimicry can help us to develop solutions that are more sustainable and that allow us to take better care of the planet and each other. Using the website 30 Animals That Have Made Us Smarter view each of the short video clips and write a 1-2 sentence summary of each. Then choose one podcast episode to listen to (there are 30+ to choose from) and highlight 3-4 big ideas to share with your teacher and class.

Video Clip	Summary
Bats	
Spiders	
Sharks	
Beetles	
Fireflies	
Kingfisher	

Title of Podcast:
Big Idea #1:
Big Idea #2
Big Idea #3:

Solving Problems and Developing Solutions: Inspiration from Nature

Name _____

Using the website "Ask Nature" (you may need to create a free account), research some of the ways that Nature solves the following problems. Highlight an innovative bio-inspired technology that deals with each.

Challenge	Examples from Nature	Bio-Inspired Human Technology
Obtaining and distributing resources	1.	
	2.	
	3.	
Creating and maintaining community	1.	
	2.	
	3.	
Processing Information	1.	
	2.	
	3.	
Your choice:		