BIOMI

MICRY

The "Natural" Intersection of Biology and Engineering

by Celeste Nicholas and Jeffrey Peterson

Prior to reading the *Next Generation Science Standards* (NGSS Lead States 2013), we viewed our state's science standards as separate categories with little overlap. For example, we never would have imagined combining standards from biology and engineering. Yet, as our comfort level with the *NGSS* increased, we began to see how "crosscutting concepts" connect seemingly distinct aspects of curriculum. These connections create opportunities for rich, authentic learning experiences. Here, we describe a project on biomimicry that uses the crosscutting concept of Structure and Function to link disciplinary core ideas from biology with performance expectations for engineering (see the standards sidebar).

Project development

Last year, we participated in the NSTA New Science Teacher Academy. We enrolled in an online engineering module, as we were unsure about how to approach design with our eighth graders. During the unit on biological adaptation, we posted this question on the Academy's discussion board: "How can we integrate biology with engineering?" The NSTA mentors suggested *biomimicry*, human-designed technologies inspired by biological structures and systems. We researched examples and quickly became engrossed with the designs that mimicked organisms' adaptations. For example, the design for Velcro was modeled after the burrs that stick to your socks when hiking. Humpback whale fins have inspired efficient "WhalePower" wind turbines. Architects studying the structure of "self-cooling" termite mounds designed buildings with sustainable climate-control mechanisms. We anticipated that students would be similarly enthused, so we designed an *NGSS*-aligned biomimicry unit in which they designed their own products based on nature (Figure 1).

FIGURE 1 Shark skin

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Teaching sequence

Introduction to biomimicry (50 minutes)

This project served as the culminating event in our studies of biodiversity and adaptation. We explained to students that they would be applying these familiar biological concepts in designing products for humans that were inspired by nature's adaptations. We introduced biomimicry by showing several video clips with examples of this type of design. We then asked students to design their own 2-D or 3-D "biomimetic" products. We distributed and reviewed the project schedule, which spanned four or five 50-minute class periods (Figure 2). Students individually completed the Introduction to Biomimicry Webquest (Figure 3) in their Interactive Science Notebooks (ISNs). They used informational websites and YouTube clips to define *biomimicry*, describe its benefits, and analyze specific examples. For an extension, students were linked to Harvard's Aizenberg Biomineralization and Biomimetics Lab, where they could read about current research in biomimicry (see Resources). Student objectives were to define biomimicry and evaluate the benefits of designs that mimic nature.

FIGURE 2 Biomimicry project schedule

Defining the problem and researching solutions: One day

Define/redefine *the problem* in your own words.
Example: I want a hovercraft.
Ask the question in biological terms.
Example: How do various animals hover?

Research the problem and possible solutions.
Record your ideas/information in your ISN.
List questions you have and information needed to solve it.
Example: How do current hovercrafts work?
Which animals hover? Which animals must hover to survive?
How does a hummingbird hover?

List topics and keywords to use in your research.
Two credible sources are required.

A good place to start is *www.asknature.org*.

Design: One day

Continue research if needed. Be sure to take detailed notes in your ISN.
Propose a solution to the problem by using biomimicry.
Example: Design a hovercraft similar to how hummingbirds hover near a flower.

Design an example of your solution.

Label all the parts of your design and materials used.

Include estimated measurements in your design.

Explain why you think this solution will work.

Describe how your design was inspired by nature.

Google presentation: One or two days

Compile and communicate your problem and design to others on a Google presentation (see rubric).

FIGURE 3 Introduction to biomimicry

How biomimicry works

http://goo.gl/eVBggV

Record your answers and observations in your ISN

1. Define *sustainability*.
2. Describe why our current technology and way of life is not sustainable.
3. List Nature's Nine Laws, described by Janine M. Benyus.

Examples of biomimicry

Identify and describe a human need where engineers found a solution in nature.

Human need -

Nature's example -

Biomimetic solution -

More examples:
http://goo.gl/i7n9t

Watch the biomimicry playlist:
http://goo.gl/hxNBRD

Additional information:
http://aizenberglab.seas.harvard.edu

FIGURE 4 *Asknature.org* screenshot

Defining the problem and researching solutions (50 minutes)

The next class period was devoted to defining a problem and looking to nature for inspiration to solve it. Students could work in groups of up to four or individually. Some groups quickly and easily navigated the research process:

"Our group realized that a large majority of water filters are not efficient and long-lasting. Most filters have to be replaced within a span of two months. We looked to many fish for inspiration. The basking shark, a filter feeder, gave us inspiration to create a long-lasting water filter." —eighth-grade student

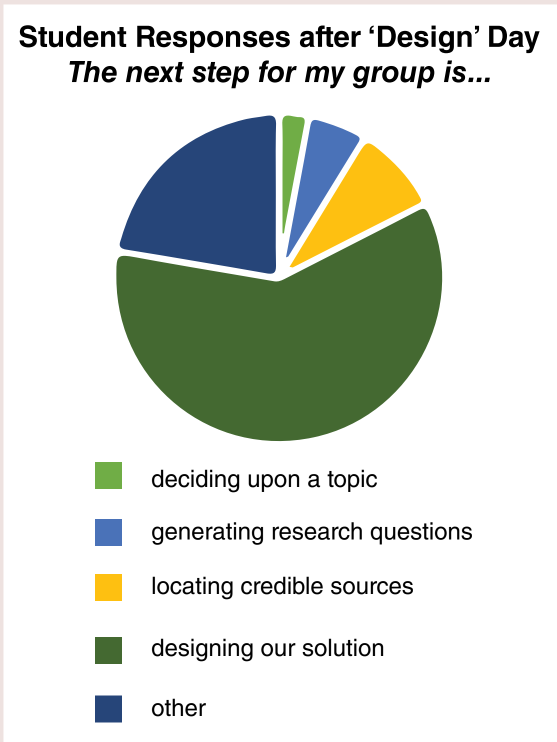
"Our topic is inspired by nature because we thought of a penguin and how it dives into water and comes out and is dry. We would like to make a wetsuit that mimics a penguin's feathers and keeps the diver dry." —eighth-grade student

Other groups had difficulty locating an organism that could solve their problem. We directed them to *asknature.org* (Figure 4; see the online version of this article at *www.nsta.org/middleschool*). Students typed their problem into the search bar and were provided with a list of organisms that solve the problem through their adaptations. For example, students who were interested in camouflage were directed to information about how chameleons, octopuses, and other animals blend into their environments. From there, students could adapt one animal's "technology" to design camouflage clothing.

At the end of class, students submitted their preliminary ideas and progress in a Google Form (Figure 5; see Figure 6 in the online version of this article at *www.nsta.org/middleschool*). This task served as a formative assessment in multiple ways. We conferenced with students and groups the next day and assisted in developing, refining, and extending ideas. When necessary, we questioned or challenged ideas. For example, a group

FIGURE 5 Google Form screenshot

FIGURE 6 Google Form graph



basing a waterproof lotion on a tree frog's skin needed to define the phrase "hydrophobic lipid bilayer" in their explanations.

Another student was designing a hydraulic-pipe repair system for planes after human blood clotting. As the blood clotting "cascade" is automatically activated by the presence of a wound, a plane could theoretically self-repair a leak in the hydraulic system (Figure 7). His research included terms such as *fibrinogen* and *polymer*. This project allowed eighth graders to dabble in biochemistry and other fields that are far beyond the scope of our curriculum.

FIGURE 7 Student diagram of a self-healing hydraulic system

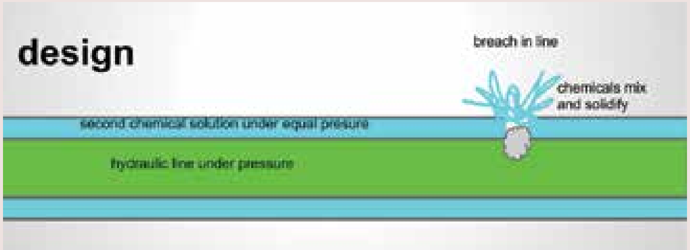


FIGURE 8 Gills

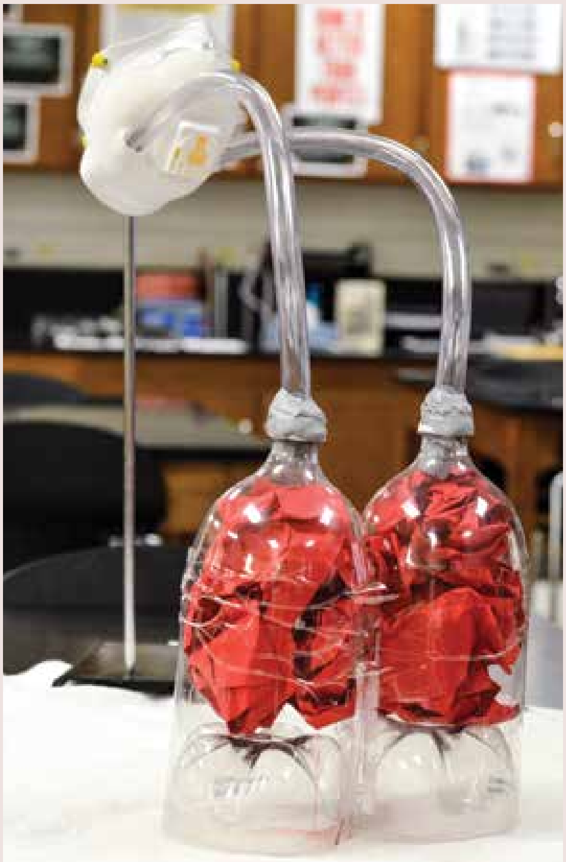


PHOTO BY JEFFREY PETERSON

We provided input on sources as well, as we required two credible sites. Most students were well-versed in research skills by this point in the year. They were proficient in using search terms effectively, evaluating source credibility, and paraphrasing scientific information. Therefore, our comments on sources were brief and easily interpreted by students. Notes such as "Where is this info actually coming from?" or "Is this a blog?" were sufficient to prompt students to seek more credible sources. We highly recommend the NSTA Press book *Front-Page Science: Engaging Teens in Science Literacy* as a comprehensive guide to teaching science and information literacies (Saul et al. 2012). Also, consider collaborating with a language arts teacher, computer skills teacher, or media specialist.

Student objectives were to define a human problem that could be solved using biomimicry, generate research questions about the problem, and locate and attribute at least two credible sources.

Biomimicry product design (50–100 minutes)

Students were required to complete a labeled 2-D diagram but they could also elect to create a 3-D representation for extra credit (Figure 8). They used classroom computers to create their diagrams. Any other materials were obtained by students. Design requirements were listed on the rubric (Figure 9). Students submitted their designs as Google Presentations to a shared Google Drive folder. You may wish to allow additional time (up to two weeks) for students to complete the design cycle with testable prototypes, additional constraints, and product redesign. Student objectives were to design a product that uses biomimicry and explain the nature-inspired features of the product and why they were selected.

Conclusion

Biomimicry naturally fused biology and engineering in a way that broadened our thinking. In the past, we saw disciplinary boundaries as firm and struggled to teach scientific processes alongside content. The *NGSS* crosscutting concepts have encouraged me to teach across those boundaries in a more efficient, integrated way. We were shocked to realize that engineering

FIGURE 9 Biomimicry project rubric (group of one to four students)

Required items	Needs improvement (3)	Good (4)	Great (5)
Problem summary	Summary does not fully explain the problem.	Summary explains the problem but does not include the question in biological terms.	Complete summary and problem are explained in detail and in biological terms.
Research	Sources are lacking or not credited.	Only one source or failure to properly credit a source.	Two credible sources used and attributed.
Inspired by nature	Nature is not mentioned in the design.	Nature is referenced, but the connection from nature to the design is not fully explained.	Describes how design was inspired by nature and how nature was incorporated into the design.
Design (diagram, drawing, etc.)	Missing many labels or measurements. Design is difficult to interpret.	Missing some labels or measurements.	All the parts are labeled. All materials used are listed. Measurements are estimated and labeled.

Extra-credit opportunity (individual students only)

Individual students can choose to build a 3-D prototype (model) of their design. The prototype must be submitted at the same time as the group project.

actually helped our students understand biology. The biomimicry task required our students to apply biological adaptation to a real-world problem. To create biomimetic design, one must truly understand how a trait benefits an organism.

The *NGSS* emphasize that crosscutting concepts are "for *all* students" (NGSS Lead States 2013) and are general so as to allow for differentiation and flexibility. Indeed, the sophistication of student thinking varied widely. Some student designs paralleled existing inventions, such as a flying squirrel suit (Figure 10) and shoes that model the traction of goat hooves. Other designs were intricate, were innovative, and operated on a variety of scales, such as the gill-raker filter and the hydraulic clotting system. Charles Darwin might even describe the range of products as "endless forms most beautiful and most wonderful" (1859, p. 490). Within this variety, the standard was approachable to all learners. This was the intention of the authors of the *NGSS*, and it was beautiful and wonderful to witness. ■

FIGURE 10 Flying squirrel suit

PHOTO BY JEFFREY PETERSON

Acknowledgments

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References

Darwin, C. 1859. *On the origin of species*. London: John Murray.

National Governors Association Center for Best Practices

Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

Standard MS-LS4: Biological Evolution: Unity and Diversity *www.nextgenscience.org/msls4-biological-evolution-unity-diversity* MS-ETS1: Engineering Design *www.nextgenscience.org/msets1-engineering-design*		
Performance expectation MS-ETS1-4: Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.		
Dimension	**Name or *NGSS* code/citation**	**Matching student task or question taken directly from the activity**
Science and Engineering Practice	Asking Questions and Defining Problems Obtaining, Evaluating, and Communicating Information	Student objectives were to define a human problem that could be solved using biomimicry, generate research questions about the problem, and locate and attribute at least two credible sources.
Disciplinary Core Idea	LS4.C: Adaptation Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions. Traits that support successful survival and reproduction in the new environment become more common; those that do not become less common. Thus, the distribution of traits in a population changes.	Students identify traits that help organisms survive and reproduce. Students apply those traits to human problems.
Crosscutting Concept	Structure and Function	Investigate how structure/function relationships in nature may be used in similar human design solutions.

Connections to the *Common Core State Standards* (NGAC and CCSSO 2010)

WHST.6-8.7: Conduct short research projects to answer a question (including a self-generated question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration.

WHST.6-8.8: Gather relevant information from multiple print and digital sources; assess the credibility of each source; and quote or paraphrase the data and conclusions of others while avoiding plagiarism and providing basic bibliographic information for sources.

WHST.6-8.9: Draw evidence from informational texts to support analysis, reflection, and research.

and Council of Chief State School Officers (NGAC and CCSSO). 2010. *Common core state standards.* Washington, DC: NGAC and CCSSO.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states.* Washington, DC: National Academies Press. *www.nextgenscience.org/next-generation-science-standards.*

Saul, W., A. Kohnen, A. Newman, and L. Pearce. 2012. *Front-page science: Engaging teens in science literacy*. Arlington, VA: NSTA Press.

Resources

Aizenberg Biomineralization and Biomimetics Lab—*http://aizenberglab.seas.harvard.edu*

Asknature.org—*www.asknature.org*

Biomimicry Institute—*www.biomimicryinstitute.org*

Biomimicry YouTube playlist—*http://goo.gl/hxNBRD*

How Stuff Works: How biomimicry works—*http://goo.gl/eVBggV*

WhalePower wind turbines—*www.whalepower.com*

Celeste Nicholas (*Celeste.Nicholas@umsl.edu*) is a doctoral student in the College of Education at the University of Missouri–St. Louis in St. Louis, Missouri. ***Jeffrey Peterson*** is an eighth-grade science teacher at Center Grove Middle School North in Greenwood, Indiana.