INQUIRY & INVESTIGATION

Using Biomimicry to Engage Students in a Design-Based Learning Activity

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Abstract

I describe a design-based learning activity that utilizes the interdisciplinary content domain of biomimicry. Design-based learning requires student creativity and technological innovation to address novel science problems, characteristics of the nature of science not often addressed in schools. Alignment with national standards documents, protocols, and assessment recommendations are provided.

Key Words: *Biomimicry; design-based learning; technology; inquiry.*

In a recent issue of *ABT*, Maura Flannery discussed the current advances in the science of biomimicry (Flannery, 2010), including the related topics of synthetic biology and biomaterial engineering. Numerous classic historical examples, such as the cocklebur-inspired design of Velcro by George de Mestral, are cited as falling under the umbrella of biomimicry as well. The article goes on to examine the transition of much of the science of biomimicry into the microscopic world, for example, where researchers have begun to attempt to actively recreate the actions of enzymes. She states: "It seems that humans have been attempting to copy nature for a very long time, and this impulse continues today" (p. 452). Biology instructors can take advantage of this "impulse" to engage their students with biology through active-learning activities as well as provide a topic that addresses many interdisciplinary science, technology, engineering, and mathematics (STEM) themes at once (Riechert & Post, 2010).

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Biomimicry is the technological application of designs already used in nature to solve problems in engineering, material science, medicine, and other fields (Mueller, 2008). In other words, biomimicry is a form of reverse engineering whereby researchers identify a problem, seek a biological source that has evolved a natural solution to that particular problem, attempt to understand that natural solution, and then redesign the solution for human benefit. The application- and design-related goals of biomimicry align with the statement of the *National Science Education Standards* (National Research Council, 1996) that students should learn the skills to "develop abilities to identify and state a problem, design a solution – including a cost and risk-and-benefit analysis – implement a solution, and evaluate the solution" (p. 107).

Design Based Learning (DBL), a teaching method centered on student design projects, emphasizes collaboration, design process skills, and hands-on learning (Kolodner, 2002; Rivet & Krajcik, 2004). The advantages of DBL are numerous and include providing a relevant forum for student learning, increasing student motivation and engagement, promoting active learning, promoting collaboration and cooperative learning, and fostering creativity (Kolodner, 2002; Doppelt et al., 2008). Doppelt et al. (2008) clarified the steps in the technological design process as follows:

1. Define a problem or identify a need.
2. Collect information about current solutions.
3. Introduce alternative solutions.
4. Choose the optimal solution.
5. Design and construct a prototype.
6. Evaluate the efficacy of the prototype.

The following article describes a short biomimetics engagement activity and a more long-term DBL project using the steps of the design process as a curricular framework (Doppelt et al., 2008). This activity was designed by the author and was piloted with and vetted by middle and high school biology teachers at a professional development workshop.

○ Biomimicry

Only recently have biology practitioners actively attempted to utilize biomimicry as a biology content focus (Reed, 2003; Riechert & Post, 2010; Weissburg et al., 2010). Here, I define biomimicry broadly, following Meuller (2008), to include the applications of natural phenomena to solve a social or technological problem. This can include solutions at the macroscale, such as the Velcro example provided above,

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or at the microscale, such as those currently pursued by synthetic biologists and biomaterials engineers. It is not my intent to rehash the thorough content coverage of Flannery (2010) that can be accessed by other *American Biology Teacher* readers. Instead, I have compiled a list of resources that have been helpful in developing the content for this activity and collecting examples of biomimetics. These resources should likewise be helpful to any instructor wishing to integrate biomimicry into their curriculum.

Publications

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- Benyus, J.M. (2002). *Biomimicry: Innovation Inspired by Nature*. New York, NY: HarperCollins.
- Flannery, M.C. (2010). Mimicking nature, or at least trying to. *American Biology Teacher*, *72*, 452–455.
- Mueller, T. (2008). Biomimetics: design by nature. *National Geographic Magazine*, April. Available online at http://ngm.nationalgeographic.com/2008/04/biomimetics/tom-mueller-text.html.
- Science Illustrated. (2008). Inspired by nature. *Science Illustrated*, July–August, 62–69.

Web Resources

- Biomimicry Institute. http://www.biomimicryinstitute.org/
- Biomimicry for Education. http://www.biomimicry.info/
- Biomimicry Guild. http://www.biomimicryguild.com
- Bioneers. http://www.bioneers.org

○ Instructional Activities

Engagement Activity

A good way to begin the class is by offering historical examples of how biological organisms have given rise to the ideas for many technological advances in human society (using the resources provided above). Point out examples that the students might have in the classroom, such as Velcro, stain-resistant pants, and so on. Show how each of the six steps of the design process (see above) was utilized from start to finish. I like to use the example of how water-resistant leaves of the lotus plants inspired the design for water-resistant and stain-resistant pants (Taylor et al., 2008). This engaging demonstration provides some background on how biomimetic design can be inspired by small-scale biological characteristics.

Next, organize students into small design groups of four or five and give each a shuffled set of biomimetic matching cards (Table 1). If you intend for these groups to remain intact throughout the extended DBL project, be sure to construct them with cultural, gender, and aptitude diversity. Explain to the students that the group diversity will promote creativity when deciding on design projects with each student bringing a unique perspective to the table.

The biomimetic matching cards should come in sets. *Organism Cards* show an organism and then provide a brief structural or behavioral definition on the back. The matching *Technology Cards* show a picture of a particular technology with a brief description on the back. The descriptions should help point the student to the appropriate match. Ask the students to match one *Technology Card* with the *Organism Card* that inspired it. Table 1 shows the cards I have used in the past, and numerous other examples can be found in the resources listed above. For the sake of clarity, each organism and technology has a corresponding number in Table 1 (these numbers would not be included on cards for student use). Both the examples and the descriptors can be modified according to the developmental level of the students.

Table 1. Example of card-matching sets.

Organism 1: Abalone [*Haliotus* sp.] shell.
Technology 1: Body armor that is just as tough as Kevlar but made out of natural materials (like calcium carbonate) that are cheaper.
Organism 2: Delicate beauty seaweed [*Delicia pulchra*] secretions.
Technology 2: Compounds called furanones block the build-up of biofilms, layers that harbor bacteria and other microscopic life. One potential application would be making contacts that are resistant to bacterial build-up.
Organism 3: Morpho butterfly [*Morpho* sp.] wings.
Technology 3: Interferometric modulator (IMOD) displays on handheld electronic devices that use microscopic layered mirrors to catch and reflect ambient light to produce pixels. The screens require less battery power and are easy to read in bright sunlight.
Organism 4: Boxfish [*Ostraciidae* sp.] skeleton.
Technology 4: The angular frame of the Mercedes is surprisingly aerodynamic. Its frame is also thick at high-stress points, protecting its lightweight structure from damage.
Organism 5: Brown rat [*Rattus* sp.] teeth.
Technology 5: Industrial blades that self-sharpen with super-hard coating that grinds against the soft inner metal during use.
Organism 6: Glowworm [*Lampyridae* sp.] light chemistry.
Technology 6: A cool light that has almost zero heat energy loss. Incandescent bulbs waste 98% of their energy through heat.
Organism 7: Mosquito [*Culicidea* sp.] proboscis.
Technology 7: Hypodermic needles edged with tiny serrations that minimize the amount of nerve stimulation and subsequently reduce pain.

Once students have attempted to match all their card pairs, I review the matches with the whole group to make sure that everyone is on the same page. Another option would be to have two of the smaller groups merge and see if they agree on the matches they have determined from their *Organism Cards* and *Technology Cards*. In the past, I have then chosen a few of my favorite examples and asked students to propose how they think researchers might have used that particular organism in the processes of designing a new technology. You might also have students reflect on this question in their science journals.

Design-Based Learning Project

The following is a description of an extended DBL experience that will provide a long-term project for students. Students will benefit most from working in the groups established in the engagement activity.

1. Define a problem or identify a need.

Student groups should begin the project by identifying and listing social problems or technological needs. They can do this by brainstorming potential problems in their group and listing these problems. Depending on their circumstances, these may be concerns of students in their personal lives. However, in order to foster a global understanding (as called for by many current national K–16 educational initiatives), I suggest that students identify larger global issues – for example, treatment and distribution of clean water in arid countries. Once students have a large list of issues, they should prioritize them within the group and submit them to the instructor for approval and feasibility. At this point, instructors might also want to assess and give formative feedback on student progress.

2. Collect information about current solutions.

The next step involves students researching current or suggested solutions for their identified problem. This can be done online if Web access is available or through the local library. Students should have a concrete idea of what technology has been (or is currently being) utilized in order to solve their identified problem. This step also allows students to adopt existing design ideas and attempt to enhance them through biomimetic methods.

The following two steps are combined in the suggested activity:

3. Introduce alternative solutions.

4. Choose and design the optimal solution.

Brainstorming again, students thoroughly discuss their potential alternative solutions. This will likely be the most difficult step. Teacher focus groups that have piloted this activity suggest having students make sure they identify exactly what they are trying to solve. For example, returning to the issue of global water shortages: is the problem that water is not being transported to the people that need it, or is the problem water sanitation? Once students have carefully identified the specific issue, they can then begin to research organisms that are good at solving this problem. For example, if water transport is the problem, what organisms are good at transporting water over long distances? If sanitation is the problem, what organisms are very good at keeping bacteria and viruses away from their internal or external surfaces?

In agreement with Weissburg's (2010) approach, I recommend that students initially take a broad approach in defining their solutions. They should not feel pressure to come up with a solution immediately, but be allowed to negotiate the uncertainty and ambiguity involved in finding creative solutions. This stimulates creativity within the group and closely models the true nature of technological innovation. Once students have come to a conclusion about the most relevant solution, I recommend that they prepare an informal presentation of this solution to the extended classroom. Within this collaborative setting, the entire class will have the opportunity to ask questions and perhaps address potential problems that the smaller group did not foresee. This sharing and critiquing of peer ideas is valuable in modeling science as a community of practice.

5. Construct and evaluate a prototype.

Once the small group, classroom peers, and instructor have approved the design, students should be encouraged to build a prototype. Depending on the scope of the project, the prototype might be to scale or represent a molecular machine (scaled up from the nano- or microscale). They could be "working" prototypes or those constructed of nonmoving parts. Evaluation of the quality of construction and feasibility of materials should be a consideration.

○ Conclusions

The use of biomimicry within a DBL framework is unique and beneficial to student learning for many reasons. First, it addresses the growing "blurring" of the lines between more traditional science domains (biology, physics, and chemistry) as well as between STEM fields. Biomimicry applications, especially at the molecular and nanoscale levels, require an integrated use of content knowledge. This exercise encourages students to go outside their comfort zone and integrate other science disciplines to see how they scaffold one another when applied to design projects and technological innovation.

This activity also highlights some of the less-accentuated aspects of the Nature of Science (NOS) and Nature of Technology (NOT), such as the role of creativity in scientific discovery, problem solving, technological design, and science as a social practice. Students engaging in this active-learning DBL project will gain a wider appreciation for NOS and NOT through implicit content that can build a foundation for improved attitudes and motivation to continue their studies in STEM fields.

Finally, this activity models the importance of the scientific community in validating and sharing ideas. By promoting collaboration and cooperative learning, students begin to build a science identity and to better appreciate the role that the larger scientific community plays in constructing knowledge.

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