NATURE'S DESIGN: USING BIOMIMICRY TO PREVENT SURFACE ICING

INTRODUCTION

This lesson plans allows students to investigate self-cleaning and water repellant manufactured and natural products. Students will be introduced to the micro- and nanostructure of such products and to the world of biomimicry through teacher facilitated instruction. Following the investigation of these products, their structure, and the role of biomimicry in modern science students will be used to complete a research project involving a "real world" problem.

LEARNING OUTCOMES

- Students will explore superhydrophobic surfaces both synthetic and designed by nature.
- Students will gain understanding of biomimicry as a way of using nature's processes for real world applications.
- Students will analyze the uses biomimetics in "real world" scientific applications.
- Students will gain understanding of adaptations in plants.
- Students will demonstrate understanding of micro- and nanoscale measurements.

CURRICULUM ALIGNMENT

NORTH CAROLINA ESSENTIAL STANDARDS: BIOLOGY

Bio.2.1 Analyze the interdependence of living organisms within their environments.

Bio.2.1.1 Analyze the flow of energy and cycling of matter (water, carbon, nitrogen and oxygen) through ecosystems relating the significance of each to maintaining the health and sustainability of an ecosystem.

Bio.2.1.2 Analyze the survival and reproductive success of organisms in terms of behavioral, structural, and reproductive adaptations.

Bio.2.2 Understand the impact of human activities on the environment (one generation affects the next).

Bio 2.2.1 Infer how human activities (including population growth, pollution, global warming, burning of fossil fuels, habitat destruction and introduction of nonnative species) may impact the environment.

Bio.4.2 Analyze the relationships between biochemical processes and energy use in the cell.

Bio.4.2.1 Analyze photosynthesis and cellular respiration in terms of how energy is stored, released, and transferred within and between these systems.

NORTH CAROLINA ESSENTIAL STANDARDS: CHEMISTRY

Chem.1.2 Understand the bonding that occurs in simple compounds in terms of bond type, strength, and properties.

NORTH CAROLINA ESSENTIAL STANDARDS: INFORMATION AND TECHNOLOGY

HS.SI.1 Evaluate resources needed to solve a given problem.

>   HS.SI.1.3 Evaluate content for relevance to the assigned task.

HS.TT.1 Use technology and other resources for assigned tasks.

>   HS.TT.1.1 Use appropriate technology tools and other resources to access information (multi-database search engines, online primary resources, virtual interviews with content experts).

>   HS.TT.1.2 Use appropriate technology tools and other resources to organize information (e.g. online note-taking tools, collaborative wikis).

>   HS.TT.1.3 Use appropriate technology tools and other resources to design products to share information with others (e.g. multimedia presentations, Web 2.0 tools, graphics, podcasts, and audio files).

CLASSROOM TIME REQUIRED

This lesson is intended for 4-5 consecutive (90 min block) class periods.

MATERIALS NEEDED

- Ketchup bottle video (or actual sample of self-cleaning bottle if available) http://youtu.be/uPJa_eZBPGI and http://www.fastcoexist.com/1679878/mits-freaky-non-stick-coating-keeps-ketchup-flowing
- Samples of self-cleaning materials and plants (i.e. 5 inch square fabric sample from stain resistant pants such as Dockers or Lee, lotus leaf, water lettuce plant, elephant ear plant, etc...)
- Samples of non-self-cleaning materials and plants (i.e. aluminum foil, glass slides, plastic, regular fabric samples, various tree leaves, etc...) *These items can vary depending on availability as long as they are flat and non-hydrophobic surfaces.*
- The Lotus Effect PPT Presentation
- The Lotus Effect PPT Presentation Guided Notes Handout
- Research Guide
- Rubric for presentation
- Airplane Crash Reading (Associated Press, 2009)

- Various Presentation Web sites:
    - Glogster--http://www.glogster.org/,
    - Voki--http://voki.com/,
    - Animoto--http://animoto.com/,
    - Voicethread--http://voicethread.com/,
    - Prezi--http://prezi.com/

TECHNOLOGY RESOURCES (RECOMMENDED)

- Internet Connection
- PowerPoint
- Microscopes (Enough for students to work in groups of 2-3)
- Projector
- Digital Camera

PRE-ACTIVITIES

Students should have basic microscopy skills in order to compare the microstructure of the plants and manufactured items. Students should have a basic understanding of measurements and metric prefixes.

TEACHER BACKGROUND

Scientific developments inspired by nature have resulted in some of the most influential inventions of our modern time. The inventor of Velcro was inspired by the burrs of plants that attach themselves to animal fur. (Benyus, 1997) Biomimicry, or biomimetics, is essentially taking inspiration from nature's designs, models, and systems to enhance human designs or solve man's problems. Besides Veclro, biomimicry has led to products such as stain resistant slacks, water resistant windshield coatings, self-cleaning paint, and non-stick containers. These inventions have been inspired by the evolution of organisms found in nature and continue to shape science and engineering in the modern world. (Eadie & Ghosh, 2011) .

This lesson focuses on the lotus effect found in nature, named for the Lotus leaf, whoses surfaces are extremely water repellant and self-cleaning. (Solga, Cerman, Striffler, Spaeth, & Barthlott, 2007) Animals, such as spiders and water striders (Gao & Jiang, 2004), can be found with water repellant surfaces similar to that of the lotus plant, making them adapt to survive in damp conditions. (Cerman, Striffler, & Barthlott, 2009) Other plant species, such as the water lettuce (*Pistia stratiotes* L.) also demonstrate these water repellent, or superhydrophobic, qualities with surface structures different from that of the lotus plant. The surface of the water lettuce is covered in multicellular hairs that prevent water and dirt from ever reaching the surface of the leaf while the Lotus leaf has a rough surface that traps air preventing water from sticking to its surface.   These qualities, among many more found in nature, are being studied and replicated on the nanoscale in order to create high-tech materials to aid in anything from non-stick ketchup bottles to ice repellent airplane wings.

This is a multimedia lesson for high school science in the 5-E Lesson format and focuses on biology, with supporting material from physical science/chemistry.

ENGAGE

Students will be introduced to superhydrophobic surfaces through video clips of anti-sticking ketchup bottles comparing them to traditional ketchup bottles (see Materials for links).

Use the following questions for discussion after viewing the video:

- How do you think this is possible?
- What do you think they did to the bottle to make it so slippery?
- How could this possibly be related to nature?
- What other areas of science could benefit from a technology like this?

The remainder of the lesson will seek to answer these questions.

EXPLORE

Students will work in partners or groups (depending on class size) to investigate various surfaces (plastic, glass, aluminum, leaf samples, stain resistant pants/fabric, non-stain resistant fabric samples, etc...) and compare their water repellent qualities, or hydrophobicity using the Student Investigation Sheet.

Notes on collecting materials:

- Material samples may vary, but stain resistant fabric and no-stain resistant fabric are the best for real world connections to biomimicry technology.
- Choose at least one hydrophobic leaf such as the elephant ear, water lettuce, or lotus leaf. These are widely available and inexpensive at local garden shops, large hardware stores, or if you are lucky you can find samples out in nature depending on where you live.
- Additional leaf samples should include a "waxy" leaf such as a Magnolia in order to add variety to student predictions of water repellent qualities.
- Other surfaces such as aluminum foil, glass slides and plastic can be chosen based on availability. Feel free to incorporate any additional materials that have interesting surfaces to compare in this investigation.

Students will make predictions prior to beginning the investigation on how each material will interact with water. They should record all predictions and data collections in the chart provided on the Student Investigation Sheet.

Following the initial investigation, students will observe these materials under the microscope and hand lens in order to collect further information about the surface and hypothesize why/how the surfaces behave the way that they do.

EXPLAIN

Students will view a PowerPoint presentation, presented by the teacher, with information regarding the science behind hydrophobic and superhydrophobic surfaces, including the micro- and nanostructures of these surfaces. Students will take notes using the Guided Notes Handout. The "Lotus Effect" will be explained as well as its relation to the ketchup video in the Engage activity.

ELABORATE

Students will read a story about an airplane crash that occurs due to wing icing (Airplane Crash Reading). A class discussion will follow revolving around the ways in which superhydrophobic surfaces might help prevent airplane icing. Students will then research this and other applications of superhydrophobic surfaces and materials. Research may be done online using internet sources. Encourage students to look for scholarly papers as well as news articles and journals. Students will be given a series of questions to guide their research in the Superhydrophobic Surfaces Research Guide

Examples of online resources for student research include but are not limited to:

- Aircraft Icing http://flighttraining.aopa.org/pdfs/SA11_Aircraft_Icing.pdf
- Aircraft Icing http://www.crh.noaa.gov/images/lmk/Brian%20S/LMK_Icing_Show.pdf
- A Pilot's Guide to Icing http://aircrafticing.grc.nasa.gov/courses.html

EVALUATE

Students will work together to come up with a proposal for either a new product or an existing product that can be improved by the use of biomimicry and super-hydrophobic surfaces. This product may deal with aircraft safety and icing or something completely different. Students should use the research that they did online to help come up with this new or improved product in order to "sell" the product to a panel of their peers. Students will present their proposal upon completion using the Presentation Rubric provided.

PROJECT GUIDE: OVERVIEW OF REQUIREMENTS AND OUTCOMES.

Student groups are allowed 45-90 minutes (depending on availability) to work towards creating a new or improved product that uses biomimicry and super-hydrophobic surfaces to improve the lives of humans.

Group members are expected to delegate responsibility amongst themselves and share workload equally. Possible roles that may be suggested to the groups may include recorder, graphic designer, researcher, technology guru, main presenter, etc...

Students are encouraged to include visuals in their presentation that portrays the product that they are proposing. Images supporting the scientific evidence should also be included. Student groups can use online platforms to accompany the presentation and display the information provided about the product. Some suggested online platforms include:

- Glogster--http://www.glogster.org/
- Voki--http://voki.com/
- Animoto--http://animoto.com/

- Voicethread--http://voicethread.com/
- Prezi--http://prezi.com/

Students will present their proposal formally to their peers, who will use the Presentation Rubric to assess their presentation. The teacher will also use this rubric to assess group presentations.

ASSESSMENT

Use the rubric to evaluate the student presentations. Post lab questions following laboratory exploration can be used for a final assessment

MODIFICATIONS

If online presentation applications such as Glogster or Voicethread are unavailable, traditional poster board and markers may be substituted as presentation visuals.

ALTERNATIVE ASSESSMENTS

Alternative assessments for students with special needs include:

- Alternative instructions in place of the rubric for students requiring additional help due to learning disability or language barriers.
- Post lab questions may be discussed as a class rather than answered individually for students that need differentiated assessment.

SUPPLEMENTAL INFORMATION

Further information on the lotus effect and its use in material design can be found at:

Nanotechnology solutions for self-cleaning, dirt and water-repellent coatings
http://www.nanowerk.com/spotlight/spotid=19644.php

Hydrophobic surface allows self-cleaning: sacred lotus
http://www.asknature.org/strategy/714e970954253ace485abf1cee376ad8

CRITICAL VOCABULARY

Hydrophobic: Lacking affinity for water.

Hydrophillic: Of, relating to, or having a strong affinity for water.

Superhydrophobic: Repelling water to the degree that droplets do not flatten but roll off instead

Surface Icing: The accumulation of ice on the outermost layer of something.

Nanometer: One billionth of a meter.

Micrometer: One millionth of a meter.

Lotus Plant: A water lily (Nelumbo nucifera, family Nelumbonaceae) of Asia and northern Australia, typically with dark pink or white-and-pink flowers.

WEBSITES

Additional resource may be found on the web at:

Biomimicry Institute: htttp://biomimicry.net/ This website provides detailed information about biomimicry with educator resources.

Biomimicry Guild: http://www.biomimicryguild.com/guild_biomimicry.html This website provides information on biomimicry and its uses in today's business market.

Important! An external website should not be *required* for a teacher to use your plan unless it is a highly stable, institutionally maintained resource.

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COMMENTS

Teacher tips and helpful hints: Be certain to take time in between each activity to summarize and ensure that everyone understands the concepts that have been introduced. Each activity builds on the previous so it is imperative that students do not fall behind before moving forward.

AUTHOR INFORMATION

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ACKNOWLEDGEMENT

KENAN FELLOWS PROGRAM

SMT
North Carolina Science,
Mathematics, and Technology
Education Center

Introduction: Scientific developments inspired by nature have resulted in some of the most influential inventions of our modern time. The inventor of Velcro was inspired by the burrs of plants that attach themselves to animal fur. Biomimicry, or biomimetics, is essentially taking inspiration from nature's designs, models, and systems to enhance human designs or solve man's problems. Besides Veclro, biomimicry has led to products such as stain resistant slacks, water resistant windshield coatings, self-cleaning paint, and non-stick containers. These inventions have been inspired by the evolution of organisms found in nature and continue to shape science and engineering in the modern world.

In today's activity you will investigate a popular biomimicry topic, hydrophobic surfaces. Big word for a simple concept! Let's break it down:

Hydro=water + ***phobic***=fearing

So, hydrophobic surfaces are just surfaces that "fear" or repel water! You have probably experienced some of these surfaces in your life and probably didn't even realize it. Today, you and your partner/partners will examine several different surfaces, both man-made and natural, to determine their level of hydrophobicity.

Materials: Collect the following materials from your teacher

- Test samples (these will vary depending on availability)
- Pipet
- Beaker or cup of water
- Hand lens and/or microscope (when available)

Procedure: Follow the instructions below to complete your investigation

1. After collecting your materials, examine each sample thoroughly. You may use a hand lens, if available, to examine the samples more closely.

2. Make a prediction of how each sample's surface will interact with water. Use the following terms to gauge your predictions:

   Hydrophillic=Not water repellent at all. (Water droplets stick to surface, spread into a thin layer over the surface; droplets do not easily roll off of the surface, even when surface is tilted.)

   Hydrophobic=Water repellent. (Water droplets adhere lightly but do not spread out much across the surface; droplets roll off of the surface when tilted.)

   Super-hydrophobic=Extremely water repellent. (Water droplets do not adhere to the surface and remain in a tights bubble on the surface; droplets roll off easily when barely tilted.)

After forming your prediction of how each surface will interact with water, record your predictions using the vocabulary terms from above, in the **Data Collection Table.**

3. Next, you and your partner/partners will place water droplets, using the pipet, on the surface of each sample. Try to make each droplet as close to the same size as possible. Observe how the water interacts with the surface of each sample. Does it spread out immediately? Does it remain a bubbly sphere? Does it roll off when you tilt it? Record your observations in the Data Collection Table.

4. Record your final conclusion, using the criteria provided while you were making your predictions. Identify each sample as hydrophilic, hydrophobic, or super-hydrophobic in your conclusion.

Data Collection Table

Material Sample	Prediction	Observations	Conclusions

5. After you have completed the water droplet tests respond to the following questions:
    a. Were your predictions correct about the way that the droplets interacted with each surface?
    b. Which surfaces surprised you? Explain.
    c. What do you notice about the surfaces that repelled water the *most*? What do they have in common?
    d. What do you notice about the surfaces that repelled water the *least*? What do they have in common?

6. Finally, examine each surface more closely using the hand lens and/or microscope to see if you can observe some possible characteristics that result in hydrophobic or super-hydrophobic surfaces, that you may not be able to see with the naked eye. Record any further observations in the space below:

Magnified/Microscopic Observations

Think About it: How does this all relate to the video you watched on the new ketchup bottles?

BIOMIMICRY: USING NATURE'S DESIGN

What is the Lotus Effect®?

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Why would a species need to be superhydrophobic? How could this benefit them?

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Make a list of species that you predict might need to be extremely water repellent.

Why the Lotus Effect?

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Why do they do this?

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What's surface roughness got to do with water repellence?

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Nano-what? So, the surface of these plants are rough on the nanoscale. What exactly does that mean?

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How can this help us?

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Biomimicry

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What other ways could we use this technology to make our lives easier, safer, or better?

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NTSB: CREW REPORTED ICE BUILDUP BEFORE CRASH

50 PEOPLE KILLED WHEN PLANE PLUNGES INTO HOME IN UPSTATE NEW YORK

CLARENCE, N.Y. — The crew of a commuter plane that fell out of the sky, killing all 49 people aboard and one person on the ground, noticed significant ice buildup on the wings and windshield just before the plane began pitching and rolling violently, investigators said Friday.

Officials stopped short of saying the ice buildup caused Thursday night's crash and stressed that nothing had been ruled out. But ice on a plane's wings can interfere catastrophically with an aircraft's handling and has been blamed for a number of major air disasters over the years.

Continental Connection Flight 3407, bound from Newark, N.J., went down in light snow and mist — ideal conditions for ice to form — about six miles short of the Buffalo airport, plunging nose-first through the roof of a house in the suburb of Clarence.

All 44 passengers, four crew members, an off-duty pilot and one person on the ground were killed. Two others escaped from the home, which was engulfed in a raging fireball that climbed higher than the treetops and burned for hours. Authorities began removing the bodies around nightfall Friday.

Two others escaped from the home, which was engulfed in a dramatic fireball that raged higher than the treetops and burned for hours, making it too hot to begin removing the bodies until around nightfall Friday.

At a news conference, federal investigators summarized information retrieved from the "black boxes" — the flight data and cockpit voice recorders — recovered from the crash site. The crew of the twin turboprop reported snow and mist and poor visibility at 16,000 feet and asked permission from air-traffic controllers to descend.

The crew noted "significant ice buildup, ice on windshield and wings," Chealander said. The flight data recorder indicated the plane's de-icing equipment was in the "on" position, but Chealander would not say whether the equipment was functioning.

The landing gear was lowered one minute before the end of the flight at an altitude of more than 2,000 feet, and 20 seconds later the wing flaps were set to slow the plane down, after which the aircraft went through "severe pitch and roll," Chealander said.

The crew raised the landing gear at the last moment, just before the recording ran out.

Doug Hartmayer, a spokesman for Niagara Frontier Transportation Authority, which runs the Buffalo Niagara International Airport, said: "The plane simply dropped off the radar screen."

"Icing, if a significant buildup, is an aerodynamic impediment, if you will," Chealander said. "Airplanes are built with wings that are shaped a certain way. If you have too much ice, the shape of the wing can change requiring different airspeeds."

But he refused to draw any conclusions from the data, and cautioned: "We are not ruling anything in or anything out at this time."

Icing a known problem

Flight 3407 is the first fatal crash of a commercial airliner in the United States since Aug. 27, 2006, when 49 people were killed after a Comair jetliner mistakenly took off from a Lexington, Ky., runway that was too short.

The crash came less than a month after a US Airways pilot guided his crippled plane to a landing in the Hudson River in New York City, saving the lives of all 155 people aboard. Birds had apparently disabled both its engines.

In general, smaller planes like the Dash 8, which uses a system of pneumatic de-icing boots, are more susceptible to icing problems than larger commuter planes that use a system to warm the wings. The boots, a rubber membrane stretched over the surface, are filled with compressed air to crack any ice that builds up.

A similar turboprop jet crash 15 years ago in Indiana was caused by icing, and after that the NTSB issued icing recommendations to more aggressively use the plane's system of pneumatic de-icing boots. But the FAA hasn't adopted it. It remains part of the NTSB's most-wanted safety improvements list.

SUPER-HYDROPHOBIC SURFACES RESEARCH GUIDE

Use the following questions to guide your online research as you investigate possible uses for super-hydrophobic surfaces. Draw from the information you have learned during your in class laboratory experiences as well.

1. In the reading about the airplane crash, how did ice play a part in that disaster?

2. How could super-hydrophobic, or non-stick, surfaces, have helped to prevent this problem?

3. In what other areas of life does icing result in hazardous or inconvenient situations? Could super-hydrophobic surfaces help in these scenarios? Explain.

4. Aside from icing, what other areas of life could be improved by the use of super-hydrophobic surfaces?

5. Are there products on the market now that could be improved with the addition of super-hydrophobic surfaces? What are these products and how could they be improved?

6. You investigated stain resistant fabrics during your exploration activity. What uses could a fabric like this have in everyday life? How could these fabrics be improved by using knowledge of biomimicry and super-hydrophobic surfaces on a nanoscale?

7. When using nanotechnology, surfaces can be engineered on a very small level. You have already learned about biomimicry and the use of super-hydrophobic surfaces on the nano-scale. What types of research is going on right now in the world of science that is based on these types of technologies? Describe some of your findings here.

8. After completing an extensive search on the uses of biomimicry and super-hydrophobic surfaces, think about which of the uses you have researched might be most helpful or profitable in today's society. For example, do you think saving hundreds of lives through improving airplane safety with non-stick wing surfaces is most important? Or, do you think that creating a more non-stick ketchup bottle like shown in the video you watched in class would be a profitable contribution to society? What other uses for this technology did you read about in your research that could be new and innovative? Brainstorm ideas in the space below.