Photographs: David Lewis

Butterflies and Biomimicry

How 10-15 year olds can put to work the unique properties of Morpho Butterfly wings to help solve human problems

By **Karen McDonald**

"BIOMIMICRY IS THE SCIENCE and art of emulating Nature's best biological ideas to solve human problems."[1] Humans have been using biomimicry for thousands of years, but only recently have we started to re-learn how nature solves problems. By using nature as a model we can create more efficient systems that have been proven to work through evolutionary time. This article will introduce biomimicry to students through activities that examine the unique properties of the wings of Morpho butterflies and how they can help us solve human problems. If we could learn to mimic the Morpho's ability to create physical iridescence, we could solve the problem of making environmentally friendly dye free paints, fabrics, cars, and electronic displays for cell phones, computers, and TVs. It has even been proposed that this technology could be used to make currency with anti-counterfeit technology that would be difficult to replicate.

Most people are unaware of the fact that butterfly wings are actually transparent. They are covered in tiny delicate scales that give them their coloration. When a butterfly wing is touched the scales can fall off. They do not re-grow scales once lost, and while removal does not hurt the butterfly, it does inhibit flight. Scales act as waterproofing. They also keep the wings aerodynamic, and are also useful for absorption of light, communication, keeping warm, and as a colorful warning to predators. The color of the scales comes from melanin for browns and blacks, while greens, blues and reds and iridescent colors are caused by the scattering of light by the shape and structure of the scales.

Morpho Butterfly

Morpho is a genus of butterfly with 80 known species. They range in size from 3" – 20" and are mostly found in tropical regions including South America, Central America, and Mexico. Adult Morphos feed exclusively on rotting fruit juices. They are solitary and mostly inhabit forested regions, but will go into sunny spots or clearings to warm up. The estimated life cycle of the Morpho is approximately four and a half months. The larvae and adults are poisonous because they sequester poisons from the plants that they eat as caterpillars.

Morphos are most notable for the extremely vibrant coloration in the males of the species, which are usually a metallic blue or green. Female Morphos are usually a more dull bluish to black coloration. Not all Morphos are blue or green; some are white or pale colored, but all morphos have eye spots or *ocelli* on their under wings. These eye spots act to confuse and alarm predators that may get too close.

Morpho Wings

The colorful iridescent green or blue of the Morpho's wings is due to the nature of its wing scales and the properties of light. There are two types of coloration you can see on the male and female Morphos' wings. The first is from light that is absorbed and the other is from light that is scattered. The absorbed light coloration includes the brown and the dark eye spots on the ventral side of the wing. These colors are produced by pigment in the scales that absorb all colors of the light spectrum except brown, which is reflected back to your eye. This is how most of the colours we see in the world are produced.

The dorsal side of the Morpho's wings are unique in that they are iridescent (more so in males), which means that depending on the angle or movement of the person viewing the wings, and how the wings move, they appear to change colors. Other examples of iridescence in the natural world include soap bubbles, oil on water, and abalone shells. The iridescence on the Morpho's wing is caused by the scattering of light from the scales, rather than absorption of light. Coloration by scattering light and causing light wave interference is called structure or physical coloration.

The scales of the Morpho's wings overlap like the shingles of a house, while at the same time each 'shingle' has a micro-pattern to it. This pattern can best be described as something like a toothbrush with softly serrated saw tooth bristles on it.

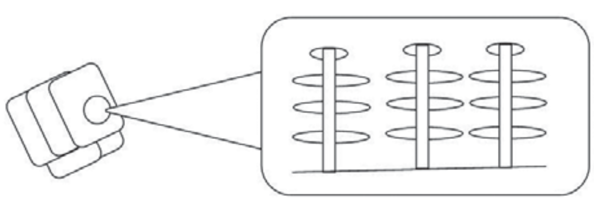


Diagram 1: *Magnified view of Morpho butterfly scales and their microstructure.*

The bristles of the brush have periodicity, meaning that they are spaced at specific intervals apart. If the bristles were spaced randomly, the wings of the Morpho would appear to be white because the reflected light would bounce around randomly.

The spacing of the scales, along with the microstructures of the wing, are critical for the iridescence, because the light bounces off of the overlapping scales and between the 'bristles' to create the angles needed for light interference (Giraldo, Yoshioka, and Stavenga 2007).

Light interference creates either a filtering effect or magnification of colors (See Diagram 2 below). In constructive interference the light waves are angled in such a way that they magnify certain spectral colors and enhance the colors you see. In destructive interference, only certain colors of light come through because the light waves (their peaks and troughs) are opposite, and thus they interfere with each other. Depending on where you're standing, and the angle that you're viewing the butterfly's wings, the reflection of the light from the interference of light waves creates the colors you see. From one angle this may appear a brilliant blue color or from another black.

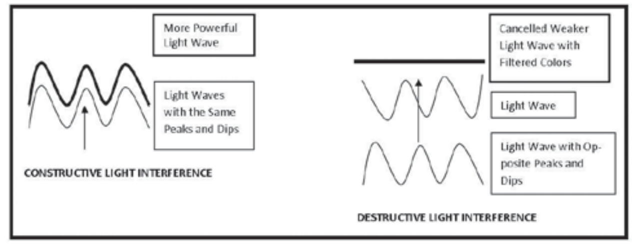


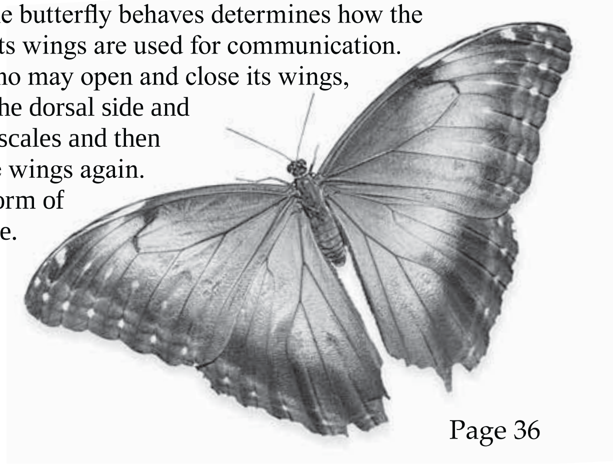
Diagram 2: *Illustration of constructive and destructive light interference.*

How Does a Butterfly Communicate?

Say you're an adult butterfly happily feeding on nectar, and constantly watching out for predators, competitors, and mates. How do you communicate, and at the same time keep from being eaten, and tell a predator you're not tasty? For Morpho butterflies, the solution is to use visual cues.

Most colors on butterflies are designed to either blend with the environment or to show off. In some cases (such as the Monarch or Morpho) the colors let predators know that the caterpillars, and thus the adult butterflies, have sequestered poisons into their bodies (by eating poisonous plants as caterpillars) and are toxic if eaten. Morphos have very dull brown undersides to their wings so that when they are at rest, or their wings are closed, they perfectly camouflage into their environment. Their eyespots startle predators by looking like a potentially larger predator's eyes. The ventral side of their wings, especially in males, is often flashy so they can catch the eye of potential mates or use their color to highlight their fitness and to defend territories. Butterfly scales rub off easily and wear off with age, so a male with lots of beautiful scales still in-tact is probably younger and more fit or is better able to evade predators and keep its wings and scales whole. The advantage of these visual cues is the limited physical interaction between rivals, allowing them to use less energy to fight and less risk of wing damage in confrontations. Females can also visually assess males quickly without using much energy.

How the butterfly behaves determines how the colors on its wings are used for communication. The Morpho may open and close its wings, exposing the dorsal side and iridescent scales and then closing the wings again. This is a form of Morse code.



Butterfly Problem Solving

Butterflies are light weight, delicate, and compact, yet sturdy enough to allow a butterfly to migrate hundreds of miles. They also take advantage of natural light to produce iridescent colors.

For humans it takes multiple layers of colors and pigments to achieve iridescence, which is expensive and often uses environmentally harmful technologies. By using ambient light and the periodicity (spacing) of their scales, scale layering, and the scale's microstructure, the butterfly can reflect light and interfere with light's wavelengths to create multiple colors without chemicals. These colors are brilliant and can be seen from many yards away.

By mimicking the Morpho's ability to create physical iridescence we can solve the problem of creating "Earth Friendly" dyes, colors for fabrics or cars, displays for cell phones, and much more. Biomimicry provides this solution.

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References

Giraldo, M.A. S. Yoshioka, and D.G. Stavenga. Far field scattering pattern of differently structured butterfly scales. Journal of Comparitive Physicology 194:201-207.

Endnotes

1. Biomimicry Institute, 2009. <biomimicryinstitute.org>

2. "Butterfly Alphabet" by Kjell B. Sandved; Scholastic Inc. 1996. Shows the scales of a butterflies and the alphabet found in the scales on their wings.

CLASSROOM ACTIVITIES

Scales Under a Scope

Objectives:

- Students will be able to explain the structure of a butterfly wing and why it is covered in scales.
- Students will draw butterfly wing scales.
- Students will be able to describe the patterns on butterfly wings and speculate about their functions.

Materials: Microscopes, one per student of petri dishes, probes, drawing paper, pencil, book with butterfly scale images, photos, etc. such as "Butterfly Alphabet" by Kjell B. Sandved[2].

Procedure

1. Find butterfly wings. It is not recommended to pursue live butterflies just to acquire their wings. Wings can be found in a variety of places, such as from dead moths and butterflies trapped on windowsills and in spider webs. You can make a class project to search out dead butterflies and moths. Make sure you tell students to minimally handle the wings. If you are collecting them, be sure to store them in a secure location away from direct sunlight and strong winds. You can also order insect specimens from biological supply companies such as Carolina Biological Supply Co. or even mounted slides for compound microscopes. If you are specifically interested in iridescent butterfly wings you can order one or two preserved specimens and cut small sections from the wings for each pair of students to use.
2. Prepare butterfly wings in Petri-dishes, one per student or pair of students. You want the wings to lie flat in the dish for better observation.
3. Discuss with students some of the information about butterfly wings and scale structure. This ideally should be done in advance.
4. Have the students observe the wings and scales. They can move the dish around to observe the colors of the wings, and then observe them under the scope. Have them compare iridescent versus pigmented wing scales.
5. Have the students draw the scales that they see and try to describe in words their textures and shapes. For younger students you can also have them color with crayons or colored pencils.
6. If you are using compound scopes be sure to have the students include as much detail as possible.

Light and Prisms

Objectives:

- Students will be able to explain how water bends light.
- Students will be able to name the colors found in the visible spectrum of light.
- Students will elaborate on the concept of bending light and how the microstructures of a Morpho butterfly's wings work.

Materials: One glass of water per student or pair of students, pencils, prisms, boxes of crayons, white paper, flashlights.

Background: To help students understand the concept of biomimicry using butterfly wings you will need to be sure that they have a strong understanding of the properties of light. These exercises

How a rainbow appears

- Rainbows only occur when light is behind you shining onto water vapor.
- The droplets of water in the water vapor slow down the white light.
- The light coming from behind you strikes the water droplet at an angle. This slows down the light. It bounced off the back of the water droplet. Then it bent and reflected out the front of the water droplet. This final reflection of the bent light through the front of the droplet breaks the light into the visible spectrum and we see a rainbow.

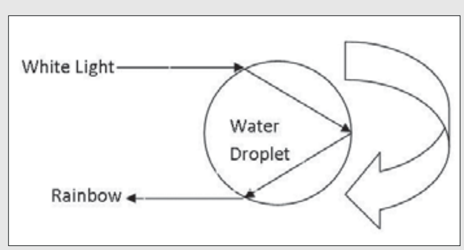

Diagram 3: *The visible light is being bent by the water droplet as the light enters the droplet the different wavelengths slow down, based on their frequency, and the colors of the visible spectrum are separated out.*

are designed to demonstrate the bending of light and the colors of the visible light spectrum.

Procedures:

A. Bending Light with Water

1. Have students fill the glasses at their stations at least 1/2-2/3 full of water.
2. Have the students hypothesize what they will see if they put the pencil into the water, by viewing from the top and sides.
3. Place a pencil in the glass and lay it against the rim.
4. Students should then observe the pencil from above the glass and then from the side of the glass. Discuss with them what they see, and how this models light refraction, or bending.
5. Explain that refraction is simply the slow of light as it enters a translucent substance, such as water, and if that light comes in at an angle (or many angles) it changes its path. This causes distortion in the image that we see. Rain drops can bend light, and rainbows are light shone through water vapor. Morpho butterfly wings, like water, bend light. In the next exercise they'll see how the colors of light are bent so they can see particular colors of the spectrum.

B. Prisms and Visible Light

1. Begin with a discussion of visible light. What color is light? Most will state that it's white. Discuss with the students that by bending light, like in the previous exercise, you can slow it down. Then explain that prisms, like water, are a way to slow down light and bend it so that you can see all the colors that comprise light.
2. Make predictions about what they might see if they use the prism.
3. If the day is bright and sunny, have the students use their prisms to catch full sunlight and reflect the rainbow spectrum onto a flat surface. If the day is dark, or you must be inside, you can use flashlights or lamps and shine the rainbow on a white piece of paper.
4. Have each student take a turn with the prism while the other partner writes down in exact order the colors that become visible. If you choose you can extend this activity by having them color a small rainbow or square of colors to help them remember. The acronym ROYGBIV is also helpful (Red, Orange, Yellow, Green, Blue, Indigo, and Violet).
5. After students complete their observations, briefly discuss light waves and refraction pertaining to rainbows and prisms.
6. Conclude this activity by referring back to Morpho butterflies. The iridesence of the male's wings is caused by the microstructures of its scales reflecting and bending light.

Bubbles and Light Interference

Materials: a 1:10 diluted soap to water solution, paper towels, one per pair of students of plastic cups, bowls, plates, and straws.

Background: For this activity we will be following up on the question posed in the Light and Prisms section of this write up, "How do the Morpho's wings bend light so that we only see one or two colors and not the entire rainbow?"

Review the following Concepts with your Class:

- White light is composed of many colors.
- Those colors travel in waves, with peaks and troughs.
- Colors such as red and yellow have higher energy waves with closer peaks and troughs, while those like blue and purple travel more slowly and have peaks and troughs that are farther apart.
- Light waves can interfere with each other either by being constructive (coming together) or destructive (canceling each other out).
- Constructive interference can be thought of as two waves of light coming together in an exact match of peaks and troughs to form a bigger and stronger color wave.
- In constructive interference you will see vibrant colors of the rainbow because the light's peaks and troughs are enhancing each other. In this exercise students should be able to see interference rings around the bubble.
- Destructive interference is when two light waves meet and their peaks and troughs are opposite. This causes the light waves to mis-match and interfere with the other's peaks and troughs.
- When you see destructive interference the colors may be muted or black. This is especially the case where the bubble is thinnest or when it's about to pop.
- An example of interference can be seen visually with water and waves. When you throw two pebbles in a pond near each other, the ripples of the water (the waves and troughs formed by the displacement of the water) from each pebble meet and slow each other down. If you throw a pebble in the water and another right after it in the exact location, the ripples of the water will become larger and more powerful; this is constructive interference. This can be demonstrated using a pan of water.

Procedure

1. Materials should already be at the student's work stations (one straw, plate, one bowl with diluted soap).
2. Have the students carefully dip their straw into the soap solution and coat the end so that they can see a soapy film.
3. Have them try to blow a bubble over the plate so that the plate catches the formed bubble. (If your students are having a difficult time making the bubbles they can blow directly into the bowl to make a bubbly mixture.)
4. The students can then make observations about the colors of the bubbles and the bands of colors that they see.
5. Ask the students to observe what happens as the bubble ages. They should see the color bands get larger, a dark spot form, and then the bubble will pop. This is constructive interference changing to destructive interference (the black spot).
6. Ask students questions about the light interference and what they think is happening.
   Optional: Use different tools and have students make different shapes of bubbles and see how the light bands change.

How Can We Learn from the Blue Morpho?

By studying the blue Morpho's wing structure we can learn to mimic how they create colors, without pigment, in an ecologically friendly way. This has the potential to help humans create more efficient technology in computer and LED displays, coloring fabrics, or fabric surfaces. Here are a few discussion questions for your students to summarize the lesson:

- What did you learn about how the Morpho creates color on its wings? Is this the same for both sides of the butterfly? Why or why not?
- How does the structure of the Morpho's wings affect how it appears?
- How are bubbles, abalone shells, and Morpho wings similar?
- What can we learn from the iridescent wings of the Morpho?
- What modern problems could the Morpho's wings help us solve? Why?
- What other questions could we ask about butterflies that might help humans solve problems?