Biomimicry: Background Information & Pre and Post Activities

BACKGROUND INFORMATION

BASIC ECOLOGICAL CONCEPTS

Ecology is the study of the relationships between organisms and their environments. An ecologist asks questions like: Where does this organism live and what characteristics make it particularly suited for that location? How does this organism get its food? What other organisms eat it? By asking questions such as these some basic principles have emerged. Understanding the following basic ecological concepts help us appreciate the complexity of life residing in and around the Bay.

Everything is related to everything else

Perhaps the easiest place to see interdependence in the environment is to look at food. All food on this planet is essentially made by plants through the process of *photosynthesis. Herbivores* are animals, which depend directly on plants for food. *Carnivores* eat herbivores. Take away all of the plants and there would be no animals. Can a plant, then, exist independently of all other organisms? No. Although it doesn't eat, a plant needs *nutrients* and is dependent on *decomposers* (bacteria and fungi) to break down dead organisms, thereby releasing these nutrients for use by the living plant.

Everything depends on something else

All organisms are also dependent on factors in the physical environment. They must have a source of water. Animals must have oxygen to breathe. Plants must have sunlight to perform photosynthesis. You can probably think of many more examples of how organisms are dependent on their environments.

Everything must go somewhere

No object ever disappears completely from the face of the earth. It may be broken down into atoms and be used to build something else, but those atoms are still there. In this way, nature deals with waste by recycling. Any plant or animal that does not become food for some animal becomes food for decomposers, which free the nutrients to be used again. Anything that cannot be decomposed must remain in the environment as it is. What are some examples of this kind of waste? The next time you throw something away, you might remember that there really is no "away" to throw it to.

Earth's resources are limited

How often do you run out of time to do what you want or need to do? Everyone knows that each day only has so much time in it, and that we have to be careful how we use it if we are going to accomplish everything we need to. The earth's available resources are like time in that we have to be careful how we use them, or they might run out. There is only so much gold, so much

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petroleum, so much fresh water, so much food, and so much space. All organisms are limited by the availability of resources, but humans have a special opportunity and a special responsibility. Although plants cannot make a decision to conserve clean water, humans can. To do this intelligently we must find out how much of each resource is available and then we must budget our use. We must also think about recycling. The earth can recycle its components naturally but humans must make special efforts to preserve the natural resources.

BIOMIMICRY

BIO-INSPIRED DESIGN DEFINITION

Bio-inspired Design, Biomimicry, Biomimetics, and Bionics are all terms that describe, generally, the same activity. That is the study and emulation of nature for the purpose of solving technological or societal problems.

HISTORICAL EXAMPLES OF BIO-INSPIRED DESIGN

Our problem solving has been inspired by nature since the Stone Age, but this activity has been established only recently as a formal method of inquiry. Below are a few historical examples:

- Leonardo da Vinci was, perhaps, the greatest practitioner of bio-inspired design, studying birds' wings, seedpods, shells and the physics of water to aid him in his invention offlying machines and other mechanisms.
- Sir Joesph Paxton designed a greenhouse at Chatsworth in England in 1849. Its pleated roof structure was inspired by the leaves of the giant Amazonian water lily. He later designed the famous Crystal Palace in 1851, a model for all subsequent light construction buildings of the modern age.
- The German biologist, Ernst Haeckel, had a great influence on artists and engineers in the1890's with his publication of "Artforms in Nature", a catalogue of plankton forms that is both beautiful and scientific.
- The Eiffel Tower's 1889 design may have been indirectly influenced by the study of natural form. Its chief structural engineer, Maurice Koechlin, was a pupil of Carl Culman, the Swiss structural engineer and bridge designer who was notably impressed by his viewing of a cross section of a human thighbone and the distribution of material that it exhibited.
- Sir d'Archy Wentworth Thompson wrote the seminal work "On Growth and Form" in 1917, and advocated a comprehensive case for the effects of external forces on the genesis of living form. His meticulous and mathematical study of natural forms is still a benchmark for excellence today.
- In 1941, Georges de Mestral observed how readily the burs of the Burdock plant stuck to his dog's fur and dreamed of a similar attachment mechanism. Ten years later, he had patented his device, Velcro (velour (velvet) and crochet (hook)).
- In 1960, the term "bionics" was first coined by Jack E.Steele of the U.S. Air Force. Since that time it has been practiced formally in the fields of engineering, medicine, product development, architecture, and industrial design.

CONTEMPORARY EXAMPLES OF BIO-INSPIRED DESIGN

- The **Shinsaken bullet train** in Japan has a nosecone that was inspired by the beak of a kingfisher. The engineer who designed it was wrestling with the problem of sonic booms as the train came out of tunnels, and observed, while birdwatching, that the kingfisher left no splash in its dive into the water. He realized that the two phenomena were the same: a solid body moving between two fluids. In the case of the train, the locomotive was moving between the air in the tunnel to the air outside it, and causing the turbulence that made the disruptive sonic boom. He decided that the kingfisher could teach him something about a perfect shape to reduce either splashes or sonic booms.
- **Lotusan paint** is a paint that is self-cleaning and is based on the characteristics of the lotus plant, famous in Buddhist lore for staying pure while growing out of mud. The plant does it by the microstructure on its waxy surface. Water droplets ride atop the bumpy surface of the leaf and collect any dirt particles, thus keeping the plant clean. The paint product has micro chips in it that mimic this structure and create the same self-cleaning property.
- Humpback Whales have scalloped edges on the front of their pectoral fins and the company **Whale Power** studied these so-called tubercles and their effect on turbulence. Turbulence is a problem with wind turbines and causes a lack of efficiency. The turbercles promote smooth laminar flow of water over the fins even at slow speeds while turning. By the same principle, Whale Power's wind blades are able to operate in light airs because of a design mimicking this form.

BIO-INSPIRED DESIGN CONCEPTS

Form and Function

Often there is a direct relationship between form and function in the natural world, and this form has been influenced by millions of years of natural selection. Understanding the context in which organisms have had to exist, the external forces acting on them, and the adaptations that have resulted (and why) are all important in practicing bio-inspired design.

Human goals may be quite different from those of natural organisms, so it is also important to be clear about the differences. Ideally, one wants to abstract basic principles observed in nature and translate those principles to the methods and materials humans can use to solve problems. For example, the magnificent tail of the peacock is thought to be strictly for sexual display and therefore for the number one goal of all organisms, reproductive success. Mimicking the structural color in the feathers is currently being developed for use in electronic devices, but the goal of energy efficient, daylight viewable displays is quite different from that of the peacock.

Unity and Diversity

There is a great diversity of form in the natural world, but there is also a surprising unity among the forms. This is due to the common information carrier, DNA, and the universal process of building proteins from simple arrays to more complex. For example, a whale, a bat and a chimpanzee all have basically the same bones in what we would call the "hand". The proportions of these bones, however, have, over millions of years of selection, been changed for the particular adaptive challenge that the creature faced, whether swimming, flying, or climbing. In the marine environment, the barnacle is a good example of this kind of adaptive change. It is a crustacean, and related to the lobster, but it now uses its "legs" to wave in the water so that food can flow into its mouth while it stays stuck to a rock.

Obeying Space, Physics, and Genetics

Forms in nature have been influenced by natural selection, but they also have had to abide by the laws of space and physics. For example, many of the branching shapes seen in the natural world are a result of reaction/diffusion processes that generate the ultimate form by randomness. It's similar to flipping a coin; "heads, go left" or "tails, go right" and then plotting the turns on a piece of paper. Sir d'Archy Thompson, mentioned above, went into great detail about the effects of physical forces on natural form. For example, how the form of an egg is a result of peristaltic action of muscles of the oviduct on the semi-plastic, and still-hardening egg. In the marine environment, the organisms you see have all been influenced by many physical factors. For instance, depth in the water affects pressure, being swept in currents creates shear, living in mud restricts movement. These forces affect form. In addition, there are only so many ways that an object can occupy space in our world whether it is living or not. Organisms have to abide by these constraints. For example, many shells are cone shaped and generated from a spiral. This shape happens to be one of the few that is physically possible if you have to grow bigger from one edge only and not change your proportions.

Bottom Up Building

Because DNA is the common and universal carrier of information in the living world, organisms are able to build an endless variety of material from a few basic parts. This is the "minimum components/ maximum diversity of products" concept. For example, the human body has only 20 amino acids, but is able to manufacture over 70,000 different types of proteins from them. How these amino acids are formed into chains, and then pleated or folded, determines the different protein functions. This is a different building process than the one technology employs. It starts with the very simple and small and builds size and complexity by adding and arraying the molecular parts in different ways. Solutions are often provided up through this hierarchy of scales from molecular to cellular to tissue to organ and beyond. In the marine environment, the sponge is a simple example of this kind of organization at the organism scale. The sponge, surprisingly, is not one animal, but a colony of many small ones. This colony performs many complex operations like siphoning water, catching food, digesting it and processing waste. If for some reason the colony is damaged and scattered about, new colonies can grow from the bits. This building organization process, from the bottom up, is programmed into the DNA of the sponge cells.

Typical Design Process

Bio-inspired design, is a human activity that involves a few critical components:

- an observation of nature, whether it's a form, a process or a system
- an analysis of how that phenomenon functions
- a judgement or insight that results from that analysis

- an application of the insight or principle to a problem that we have, whether technical or societal.

A typical design process has a lot in common with the scientific method, generally starting with a question or problem statement (often called a "design brief"), continuing with a test of proposed solutions, and then a revision or refinement of these proposed solutions. Much of this refinement is informed by the feedback the designer receives from the client and those who have to make the product or provide the new service. In the case of bio-inspired design, biology, engineering, and materials science are also important sources of information for the designer as he or she refines the design.

There are two main approaches to bio-inspired design:

1. The designer starts with a problem and searches in nature for a solution. An example would be the Japanese bullet train mentioned above.
2. The designer starts with a natural inspiration and invents an application for it. An example would be Lotusan paint, also mentioned above. In this case, a researcher, Wilhelm Barthlott, discovered the "lotus effect" after years of botanical investigation, and then searched for the best industrial application.

Within these two approaches are quite a few variations, among them are:

- looking to extreme cases
- finding examples of successful strategies that are comparable but that developed in completely different circumstances (called "convergence" in biology)
- balancing outcomes of a proposed solution (often called "optimization").

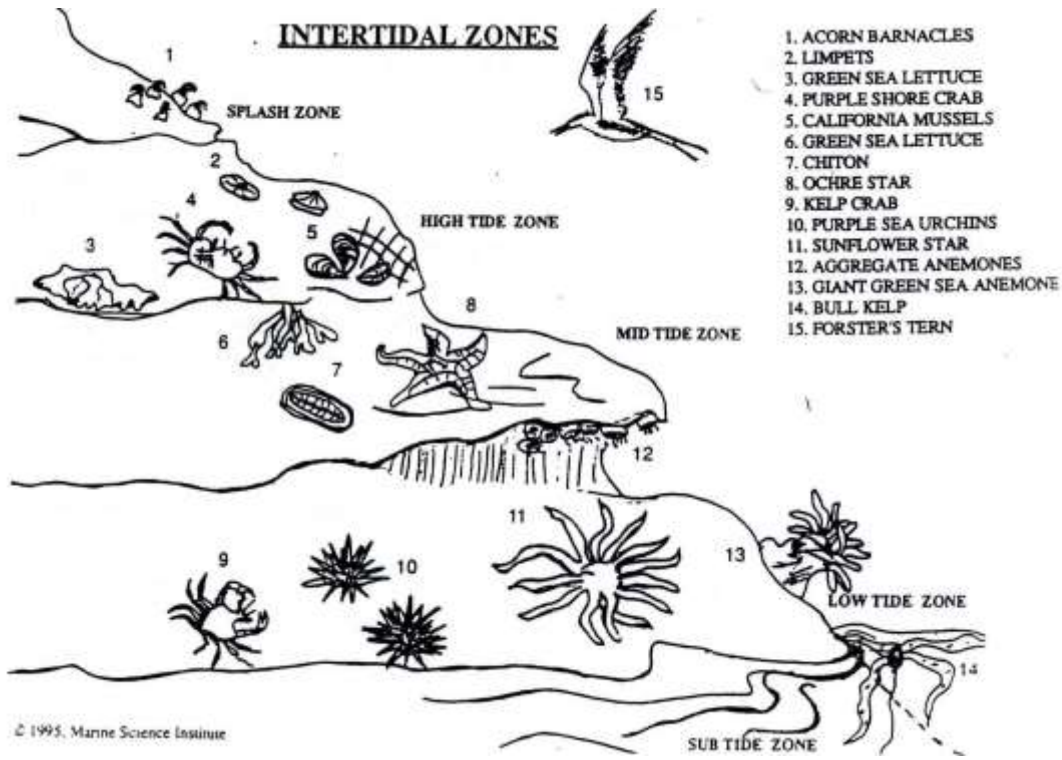
The Biomimicry Institute outlines a process that they have called the "design spiral" that you may find useful. It provides a step-by-step guide for following the general approach described above.

THE ROCKY SHORE

The rocky shores along the Pacific Coast have some of the world's richest intertidal life. The animals brought to your classroom are found mostly between Santa Cruz and San Francisco. These rocky shores consist of layered shale leading up to steep cliffs. The changing tide levels often form tidepools, which are home to a huge diversity of marine invertebrates.

THE INTERTIDAL ZONES

Intertidal animals, by definition, live between the high and low tide zones. These are regions of constant and radical change. During high tide the animals and plants are underwater, but during low tide they are exposed to pounding waves, drying wind, rain that dilutes salinity, and air, which can be very hot or extremely cold. In addition to these problems, intertidal animals are also exposed to predation from the land animals such as sea gulls, sandpipers, and humans. It's a tough life, and in order to survive, intertidal dwellers have gradually adapted to these kinds of adversities. The intertidal zones extend from the highest wave-splashed rocks down to levels that are only uncovered by extreme low tides. There are five basic zones: the splash zone, high tide zone, middle tide zone, low tide zone, and subtidal zone.



The splash zone is the uppermost zone that is closest to the cliff area, and is only partially covered during very high tides. It receives wind-blown spray, which moistens animals such as blue-green algae, periwinkles, limpets and acorn barnacles.

The high tide zone, bordering the splash zone, may be exposed for 12 hours at a time. This area may have large rocks and boulders, which during winter storms can pound the animals at this level. Animals found here include lined shore crabs, California mussels, hermit crabs, and turban snails.

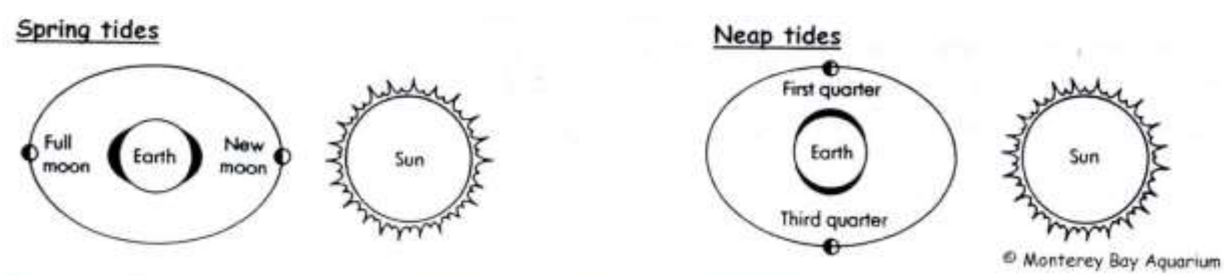
The middle tide zone covers the area between the high tide zone and the "zero" tide line. This zone is less physically stressful, as exposure may last for 12 hours or less. The animals found in this zone are adapted to the daily tidal rhythms and may actually require it to survive. Ochre sea stars, mussels, gooseneck barnacles, and purple sea urchins are a few of the species found here.

The next level is the low tide zone, and is often only exposed during times of the new or full moon. It is during this period of the lunar cycle that the tides are most extreme. Consequently, the low tide zone is exposed during only the lowest tides. This zone is often the largest and has a complex diversity of animals competing for food and room to grow. Here, clinging animals are again apparent. Anemones resist drying at low tide by contracting their delicate feeding tentacles. Sea stars can be found in clumps under rocks, using their tube feet to hold on. Mussels attach themselves to rocks by secreting tough byssal threads.

The subtidal zone, as the name implies, is almost never uncovered by water; therefore animals that are unable to tolerate air exposure for any length of time live in this area. The space is crowded with animals and competition for food and space is fierce.

ABOUT TIDES

What can be found along the shoreline, and even what the shore looks like will depend a great deal on the tides. The rhythmic rise and fall of the ocean and other large bodies of water are due mostly, but not exclusively, to the pull exerted on the water by the moon's gravity. Tides are influenced by additional forces including the sun's gravity, the earth's centrifugal force, the shape of the coast, and the ocean bottom. The highest and lowest tides, called spring tides, occur every two weeks near the times of either full or new moon. These extreme tides occur because the moon and sun are in line with the earth and the gravitational pull from each combine. Between periods of spring tides there are less extreme tides, called neap tides. During this time, the sun and the moon are at right angles to each other, and their pull tends to cancel each other. The low spring tides are the best for exploring the intertidal zone, since most of the area will be exposed.



GENERAL INTERTIDAL INVERTEBRATE CHARACTERISTICS

An invertebrate is an animal without an internal supporting structure, better known as a backbone. As a group, the invertebrates are highly successful in the natural world and well adapted. They are found everywhere: on land and in the soil, in freshwater, in saltwater, and in the bodies of other animals. In fact, invertebrates make up 97% of all the animals on the earth.

Rocky-intertidal animals are numerous, easy to find, and very spectacular with bright colors and strange shapes. They appear in such abundance in the intertidal zone that the main limiting factor is space or room for organisms to attach, cling, crawl, hide, and burrow. They are characterized by features that help them to do the above, and also ways to survive the cruel daily battles of living in a tidepool.

SCIENTIFIC CLASSIFICATION

Phylum Arthropoda

Arthropods possess an exoskeleton made of calcium carbonate, jointed appendages, and antennae. This is the largest single phylum, comprising eighty percent of all animal life, with over one million described species. Crabs, insects, shrimp, and spiders are examples of arthropods.

Class Crustacea

The crustacean body is divided into a head, thorax, and abdomen. The head has antennae, mouth-parts and eyes. The thorax is covered by a hard, plate-like carapace. Sometimes the head and thorax are fused into a single unit. Here are some examples of crustaceans: hermit crabs, purple shore crabs, lined shore crabs, yellow shore crabs, and acorn barnacles.

Phylum Mollusca

There are a variety of classes of mollusks represented in the intertidal zones. Mollusks are the second largest group of invertebrates. They have a soft body divided into a head, a foot, and a visceral hump, which contains the internal organs. The body is usually protected by a hard shell, which is secreted by the mantle.

Class Bivalvia

Clams, mussels, and scallops are examples of bivalves. They are filter feeders, and use their gills for both feeding and respiration. The shell is divided into two halves, of roughly equal sizes.

Class Gastropoda

Snails, limpets and nudibranchs (sea slugs) are examples of animals in the class Gastropoda. They have one shell or no shell, and they have a soft, muscular foot used to creep along or cling to the surface of rocks.

Phylum Cnidaria

This phylum includes sea anemones, jellyfish, corals, sea pens and hydroids. Cnidarians have a circular body plan, which is referred to as radial symmetry. They possess a crown of tentacles equipped with stinging cells that are arranged around the circular body. The main group found in the intertidal zone is the class Anthozoa (sea anemones).

Phylum Echinodermata

These animals have characteristic spines which are hard calcareous projections of their skeleton. The echinoderms possess an internal skeleton that is made of interlocking calcite plates. This is similar to our own skeletal structure. They usually have five-rayed symmetry, and move with their tube feet. Tube feet are long flexible appendages tipped with a suction cup. These are hooked up to a water system and hence, function in the presence of water. Most intertidal zone echinoderms belong to the Class Asteroidea or the Class Echinoidea. Examples include the sea stars and sea urchins.

Phylum Chordata
These animals all have a hollow nerve chord running though their bodies. The Class Chordata is divided into seven Classes, including the Mammal, Birds, Bony Fish, and Sharks and Rays. In this station we will look at the Class Osteichthyes, also known as bony fish.

GLOSSARY

ADAPTATION	Modification of an organism in order to survive within its habitat.
BIODEGRADABLE	Something capable of being broken down to simple compounds, especially into harmless products, by the action of microorganisms.
BIODIVERSITY	The richness, abundance and variety of life across all trophic levels of which all ecological systems, including the planet earth, are comprised.
BIOMIMICRY	From the Greek, "bios" life and "mimesis" imitation. The use of nature as a model, measure and mentor in order to solve problems. Bio-inspired Design is design or problem-solving that abstracts principles from nature and applies them to human challenges.
BIOMORPHIC	From the Greek "bios" life and "morph" shape. The quality of having a form or shape or behavior that is suggestive or imitative of life.
BIO-UTILIZATION	The use of living organisms to do work. An example is the use of algae to produce biofuels.
BIVALVE	A Mollusk having two shell hinged together. e.g. clam, oyster and mussel.
BYSSAL THREAD	Tough threads of protein secreted by a gland in the foot of the mussel and used to attach it to rocks, piers etc.
CAMOUFLAGE	Method of hiding in which organisms blend in with their surroundings.
CARAPACE	In crustaceans, a hard portion of the exoskeleton that covers the fused head arid thorax.
CARNIVORE	An animal that consumes other living animals.
COMMUNITY	A group of plants or animals living in the same area and depending on one another for survival.
CONSUMER	An organism that gets its nutrients by eating other organisms.
CONVERGENCE	In Biology, when two genetically distinct species evolve identical or closely similar adaptations to environmental challenges.
CRUSTACEAN	An animal with a hard outside shell, antennae, mandibles and compound eyes. e.g. crabs, shrimps and barnacles.

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DECOMPOSER	An organism that breaks down organic material and releases simple substances usable by other living things. Examples of decomposers are bacteria and fungi.
DECOMPOSITION	The breakdown of substances into inorganic forms.
DEPOSIT FEEDER	An animal that feeds by ingesting substrate and filtering out the small organic particles on the substrate.
DETRITIVORE	An animal that eats detritus.
DETRITUS	Dead plant and animal material.
DNA	A chain of molecules, provides the information for proteins, also molecular chains, to do the work of living: growing, repair and reproducing. How these chains were formed, in what sequence the nucleotides were arranged, determines what information that the gene (a string of three-nucleotide codons) has and therefore the job the protein does. DNA can be thought of as a recipe, rather than a blueprint. It starts a series of events like assembling ingredients and then mixing them in order, as a cook would, rather than prescribing a final outcome, like an architect's set of drawings. This is an important concept for understanding how nature builds and maintains itself. Growth, movement, response to the environment, and adaptation, all important attributes of living things, are all made easier if you work with an adjustable recipe, rather than an unchangeable plan.
DISSOLVED OXYGEN	Oxygen that has dissolved in water and can be used for respiration.
ECOLOGY	The study of relationships between organisms and their environment.
EMERGENCE	Emergence is the expression of a structure or pattern as a product of its parts and their interactions with each other. The resulting phenomenon is novel, much more than its parts and cannot be explained by an examination of each of them. • The double helix of DNA is an example: examination of each of the four nucleotides that comprise DNA cannot explain the complex functions that it performs. The complex shape of the double helix that is constructed cannot be predicted by the individual instructions. • Another example is your mind: its thought cannot be explained by an analysis of a neuron. Thought results from the electrochemical impulses of millions of neurons interacting with each other. • Emergence is a key concept in understanding the complexity and processes of Nature. Many of the forms seen in Nature, although complicated, have been constructed from simple sets of instructions or algorithms and their interactions. This

	concept is closely allied with the notion that Nature "builds from the bottom up" or in a small component based fashion that eventually produces complex structures.
ENVIRONMENT	The sum of all physical and biological factors that affect an organism.
EXOSKELETON	A hard encasement deposited on the surface of an animal, such as the outer covering of arthropods that provides protection from abrasion, predation, desiccation, etc.
FEEDBACK	Feedback describes the situation when output from (or information about the result of) an event or phenomenon in the past will influence an occurrence or occurrences of the same(i.e. same defined) event / phenomenon (or the continuation / development of the original phenomenon) in the present or future. • A well-known example is a typical household thermostat that switches off the boiler when heat expands a bimetal strip. A feedback loop requires three things: a "desired" or pre-programmed state or behavior, some type of sensor to determine whether that state is being achieved, and some mechanism that changes activity if there is a difference between the current state and the preset state. • Feedback is found throughout the living world at all scales: growth, regulation, and response, from the interaction of proteins in cells to the interaction of organisms in complex ecosystems. • In the world of technological innovation, feedback is what makes something "smart" whether it is an autopilot on a ship, or a macro software application on a computer, or an automatic climate system in a building.
FILTER FEEDER	An animal which extracts food particles by straining the water. Examples of filter feeders are clams, oysters, sponges and some fish.
FOOD CHAIN	A sequence of living organisms in an ecosystem in which members of one level feed on those in the level below and in turn are eaten by those in the level above them.
FOOD WEB	An assemblage of organisms in an ecosystem, including plants, herbivores and carnivores, which shows the relationship of "who eats whom."
FOOT	The wide, flat or wedge-shaped muscle of mollusks used for crawling, adhering and/or digging.
FORM	The sensorily perceivable shape, outline, or mass of an object (see Process, System as two other phenomena that we can describe in the sensory world). The concept that the form we see in the natural world has been affected greatly by the work that the organism, or

	its parts, has had to do. Through natural selection, successful forms have been able to do more efficient work and therefore survive to reproduce.
GILL	An organ used for underwater breathing or respiration by fishes and some invertebrates.
HABITAT	The particular area in which an organism normally lives.
HERBIVORE	An animal that eats plants.
HIERARCHY OF SCALE	The concept of problem-solving in nature through a range of scales, from atom to molecule, cell, tissue, organ, organism, population, community, ecosystem, biosystem. An example is a tree that is working at all scales to produce sugars, whether in its branching boughs, bending leaves, light collecting cells, or enzymatic molecules.
INVERTEBRATE	An animal without a backbone.
MANTLE	An outer sheet of fleshy tissue (in mollusks) secreting the shell and forming the chamber to enclose the internal organs.
MOLLUSK	The second largest Phylum of animals. Mollusks have soft bodies, a foot, visceral mass, and a mantle. Most also have a shell made of calcium carbonate. Snails, clams, slugs, squid and octopus are examples of mollusks.
NEMATOCYST	In cnidarians, stinging capsules used in defense and gathering food.
NUTRIENTS	The raw materials necessary for continuing life processes.
OMNIVORE	An organism that eats both plant and animal material.
PHOTOSYNTHESIS	The process used by plants to make food; in this process light energy is used to combine carbon dioxide and water to make carbohydrates (sugar and starch); oxygen gas is given off as a by-product.
PHYTOPLANKTON	Algae, usually microscopic, which freely drift in the sunlit portions of the water column.
PLANKTON	Drifting aquatic plants and animals; the adjectival form of plankton is planktonic, and a planktonic organism is called a plankter.
POLLUTION	Harmful impact on the environment resulting from human activities.
PREDATOR	An animal that captures other animals for food.
PREY	An animal caught for food.
PROCESS	A series of events to produce a result, or, in problem solving, a series of steps and decisions that produces work (see Form, System as two other phenomena that we can describe in the sensory world).
PRODUCER	An organism that makes its own food; an example of a producer is a green plant.
RESPIRATION	Process used by animals and plants to release energy from food; this process requires oxygen and releases carbon dioxide and water.

SALINITY	The amount of salt in the water. Measured in parts per thousand.
SCAVENGER	An organism that is an opportunistic feeder; scavengers usually include dead and decaying animal flesh in their diets.
SELF-ORGANIZATION	Self-organization is a process of attraction and repulsion in which a system, usually an open system, increases in complexity without the influence of an outside force. An open system in the natural sciences is one in which both energy and matter can flow in and out of. It is ubiquitous in the natural world; an example is a colony of termites that builds a nest based on the behavior patterns and responses of the individual animals.
SIPHONS	The feeding tubes used by some bivalves (clams and oysters) to filter plankton.
SPECIES	A population of plants or animals that are able to produce viable of with with each other and not with other species.
SYMMETRY	Correspondence in size, form, and arrangement of parts.
SYSTEM	From the Latin, "systema", a whole compounded of several parts in a composition. A system is an interconnected set of elements that is coherently organized in a way that achieves something. Its basic parts are: elements, interconnections between them, and a purpose or function (see also Form and Process as two other phenomena that we can describe in our sensory world).
TENTACLE	A slender, flexible appendage.
TUBE FEET	In echinoderms, hollow appendages filled with water and operated by the water-vascular system. Used for attachment, movement and the capture of water.
TUBERCLE	Small, round bumps that increase the surface area of the skin.
VERTEBRATE	An animal with a backbone. The back bone can be made of bone or of cartilage like in some fish (sharks and rays).
WATER-VASCULAR	A system of canals, bulbs and appendages filled with sea water. This system is involved in locomotion in echinoderms.
ZOOPLANKTON	Animal plankton

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PRE-VISIT ACTIVITIES

You may want to ask your librarian to set aside ecology or marine science books for your class, or ask students to bring books and magazines from home to share.

ANIMAL ADAPTATIONS

Have your class research and discuss how marine animals protect themselves from their predators or what adaptations they have to become better predators. Have the class team up in small groups and be responsible for researching one phylum. Within each group, each student can choose one animal from this phylum. They can use books or any other resources to put together a report.

CAMOUFLAGE CRITTERS

Discuss the concept of camouflage, its usefulness to an animal, and perhaps how it evolved through natural selection. Have students draw an animal camouflaged for a particular environment (forest, meadow, stream bottom, etc.) Or, choose environments on the school grounds and create a critter (from paper, clay, pipe-cleaners, even raw vegetables!) that is camouflaged in those surroundings.

Hunt in the 'hood (Grades 5-6)

(adapted from the www.BioDreamMachine.org lesson plan, "Hunt in the 'hood")

Part 1

Objective: For students to observe patterns in nature and to think about the reasons and causes behind them

Show your class that there are a few basic shapes in nature that seem to recur. Among them are: the spiral, three-way branching, and the radiating or starburst pattern. Have your class go out into the schoolyard or school neighborhood and collect at least one artifact from nature that exhibits each shape. Students should make sure not to harm anything that is living. These artifacts could be leaves, stems, seeds, small insects, etc.

Discuss:

- Why the shape is the way it is: what forces might have acted upon it to make it that way?
- What function is this shape good for?
- What product or service in the technological world could benefit from your ideas about this shape?

Part 2

Objective: For students to practice the design process involved in inventing and to present their ideas

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Have your students brainstorm possible inventions that could be made based on their observations in Part 1. The students should then draw their inventions showing their ideas from the top (plan view) and the side (elevation), on minimum 11 x 17" paper, with lots of notes to explain how they work. Have them present these drawings to the rest of the class in 3-5 minutes each, with questions and answers afterward.

Part 3
Objective: For students to learn how to constructively criticize an idea

Have your students exchange their drawings of inventions. For homework, they are to research the organism that their classmate's invention was based on, and see if they can learn anything about the creature that would add to the invention idea. They are also to analyze the application that it was intended for. The students should take the following questions into consideration

- Is it a good idea?
- How could it be better?
- Is this the best use of this feature of the organism or is there another application that would be better?

When they return to class, they are to give brief presentations about:

- what they found out about the organism
- how this new information will help improve the invention.

They should be required to draw their own additions or revisions on their own paper and pin these up next to the original design. In addition, they should be required to summarize their conclusions in 2-3 written paragraphs. Original authors should take the "catbird's seat" in the front row when their work is reviewed and be ready to explain their ideas in a collaborative way.

Activities/Curriculum links:

http://www.noaa.gov/resource-collections/hands-on-science-activities
https://www.teachengineering.org
https://sc.club.northwestern.edu/program/curriculum/

POST-VISIT ACTIVITIES

WRITING THANK YOU LETTERS

Write letters to the instructors and/or your class sponsor to tell them about the trip. When we receive letters and pictures back from the kids our instructors remember what a thrill it is to be teachers. The sponsors also enjoy getting direct feedback from the class and teacher to reinforce that they are making a difference for kids learning science. Please include the day, date and time of your trip so we can try to remember your group a little better.

Choose a Champion (Grades 5-6)

Objective: To understand the function of an adaptation and that there are many ways to solve a problem.

During the program students learn about the environment of the bay and some of the different ways that organisms have adapted to the bay's physical challenges. In this homework activity, students in teams of 2 or 3 are to be assigned a particular challenge, and asked to research 3 different ways that different organisms had responded to the challenge either in form, process, or by use of a system. They are to prepare three simple reference cards on 8.5 x 11 inch cardstock. Each card is to have the challenge, organism name, a diagram or image of the organism, and notes explaining how the organism's adaptation (its features or behavior) met the challenge. Team names should be on the back of the cards.

When students return to class all the cards will be shuffled and pinned up on a wall, and everyone will be given sticky notes or colored circles with which to vote for the 2 most successful organisms. Students should make a personal mark on their "stickies" so that if they change their mind during the voting they can switch their vote. When the votes are tallied the class will discuss why these organisms were thought to be the most successful.

Here are just a few examples of physical challenges that organisms have adapted to that you might assign to the students:

- resisting pressure from the weight of water
- adjusting buoyancy
- living in mud
- hiding from predators
- collecting food without moving
- detecting prey
- resisting cold
- getting around in the dark.

Cartesian Diver (Grades 5-6) (Post Activity)

During the voyage students learn about several different kinds of bony fish that are in San Francisco Bay. All of these fish possess a swim bladder, an organ that enables them to adjust their vertical position in the water column. It is just one of many different strategies that organisms use to get up and down in the underwater world. Buoyancy, sinking and floating are phenomena that are caused by the density difference of an organism relative to the fluid it is in.

Objective: This activity demonstrates how pressure affects density and therefore buoyancy, and how buoyancy affects the position of an object in the water column.

Supplies - Needed per student or team:

- Plastic soda bottle (1 or 2 liter)
- Eyedropper or pipet (the diver)
- Water
- Paper
- Markers

Directions

1. Fill the plastic bottle to the VERY top with water.
2. Fill the glass eyedropper 1/4 full with water- it is now the diver.
3. Place the diver into the bottle. The eyedropper should float and the water in the bottle should be overflowing.
4. Seal the bottle with the cap with the diver inside.
5. Squeeze the sides of the bottle. Note the movement of the diver when the bottle is squeezed and released
6. Squeeze again and observe the water level in the eyedropper.

Let the students practice making the diver go up and down without making it look like they're squeezing the bottle.

Squeezing the bottle causes the diver to sink because the increased pressure forces water up into the diver, compressing the air at the top of the eyedropper. This increases the mass of the diver causing it to sink. Releasing the squeeze decreases the pressure on the air at the top of the eyedropper, and the water is forced back out of the diver.

After this demonstration:

1. Have them diagram the forces that they just observed and the reactions.
2. Have them discuss:
    a. How would they redesign any of their underwater marine research stations using this phenomenon?
    b. How could adjusting pressure and density be used to move the station around? Keep it in the same place? Can they think of other ways that the station could take advantage of these laws?

Drag Race (Grades 7-8)

During the voyage students learn about drag and how it is an important factor in the performance of different shapes in fish.

Part 1

Objective: To create a "fish" for drag testing

Supplies- equal amount (by weight) to each student or team

- Clay
- String
- Small eye bolt

Directions
1. Show students different profiles of fish from the voyage
2. Have students sculpt in clay the fastest fish shape.
3. Have students embed the eyebolt, with the string attached, into the center of their “fish”.

Part 2
Testing: How fast are the fish
Objective: To understand the relationship between drag and shape

Supplies:
- Ten foot vinyl rain gutter, sealed to serve as test basin
- Sewing thread spool or other article to serve as spindle
- Metal coat hanger, bent to shape, to serve as axle for the spindle
- A small weight to serve as the pulling force
- Stopwatch
- Measuring tape

Directions
1. Secure the rain gutter to a table over which one end extends. At that end, affix the coat hanger/thread spool to the gutter. The spool spins on the coat hanger like a wheel on an axle.
2. Fill the rain gutter with water.
3. Near the end opposite the spool a ‘start” line is marked and the distance measured to a “finish” line which is marked near of the end of the gutter that overhangs the table.
4. To test the speed of each fish, the weight is attached to the end of the string and held at the spool (over which it will ride), while the fish is held ready in the water at the start line with the string taut. At the same time:
    - Let go of the fish
    - Drop the weight
    - Start the stopwatch
5. When the fish has crosses the finish line, stop the watch and record the speed. Speed equals the measured distance the fish traveled divided by the time it took. Feet per second will be most familiar to students.

Things to fuss with include adjusting the length of string to the distance the weight is able to drop before hitting the floor, making sure the eyebolts are embedded securely, and coordinating the letting go of both weight and fish. One additional rig you might set up is a “T” embedded into the fish from the top that keeps the fish at a consistent depth and rides along the edges of the gutter. This could be made with 2 craft sticks and some rubber bands and might be helped by greasing the gutter edges.

Crabwalk (Grades 7-8)
During the voyage the students observed a crab at the mud station. This is just one of many invertebrates that scientists have used as inspiration for robot design. Studying how animals move is called biomechanics and it is essential to designing robots inspired by nature.

In this activity you will ask teams of three to study the form of the crab and its behavior while walking. They will then make a model of a crab and a runway for the crab to walk on. They will then make a stop-motion film or flipbook of the crab walking and a diagram of its walk. Stop motion is a technique of taking still photos of an object, like a claymation character, in sequence and in different positions and then running the image frames together to effect motion. A flipbook does the same thing on paper, starting the first frame from the back and allowing a reader to flip the pages quickly to get the motion effect.
The model crab should be an abstraction of the real thing and can be very basic, as long as it mimics the hinging ability and form of the crab's legs. It can be made of any material that allows the legs to hinge and move in the same way as the animal. Materials could be commercial toys like Zoobs, Tinkertoys or Legos, or they can be ordinary craft or stationery store supplies. It should be made of a size that fits the runway described below. The walking legs should be numbered 1-8 so that students can record where they touch on the runway. The runway should be a 2 foot x 1.5 foot wide flat surface with a 3 inch tall x 6 inch long bump that spans the runway width at the mid distance. One side along the length of the runway should be marked at every inch, or can be covered with inch grid paper.

Students can study real crabs in the field or a video of a crab walking such as shown on this link:
http://www.youtube.com/watch?v=NAA7GOUTB4s&NR=1

Or this Science Screen Report: The Amazing Red Crab of Christmas Island:
http://www.youtube.com/watch?v=LNKgh6TfWXo&feature=related

some slow motion:
http://www.youtube.com/watch?v=tJSFTeKG_OE

After studying the video, they will decide how to position the legs at each change and in what directions the legs move in order to get the model crab from one end of the runway to the other. At each position, some legs will be touching the ground and some will not and this should be plotted and numbered on the runway. They will take a camera shot of each position from the same location. They should be encouraged to work out lighting and camera position to best advantage. Camera images can be printed on paper and placed in sequence in a flipbook, or imported into an easy to use software program like MacIntosh iMovie. Encourage a music track that interprets the crab's motion, titles and captions, and images that document the process the students undertook.

When the work is done, have a movie or flipbook festival. Compare the different motions shown and swap ideas about the mechanics of the crab and movie-making.

5. Part 1: Home Sweet Home (Grades 7-8)
In ecology, a niche is a location where an organism makes its home and what the organism does to survive, or "where you live and what you do for a living". On the Discovery Voyage students are asked to design a marine research lab, where scientists will have to live and work.

Objective: Students will learn how much space they need and what they do within it by diagramming their daily life.

Have your students make a study of their living quarters by measuring areas of activity and then diagramming their behavior within the space:

1. How much space do you use to: eat, sleep, bathe, void your wastes, socialize, work? Measurements should be of the activity areas and not just the rooms. Sometimes these will overlap.
2. When you are home, what paths do you take between these areas? Record your path on three separate days, make notes about what you are doing and with whom and when. Tally up the time you spend on each of the basic activities.
3. Draw a simple diagram of your activities using boxes for activities and lines between them showing paths to and from them. Rank your activities into five categories according to how much space you need to do them and note where they are located in relation to the other areas. Cut out five different size rectangles for your activities according to this ranking and label them (eating, sleeping, studying, etc.). Now color code these boxes according to how much time you spend doing them: red, orange, or yellow for most to least. Move them around on a sheet until they represent the distance and direction they are from each other in your daily life. For example, if you spend a small amount of time tinkering in the garage, this might be a large box (needing lots of space), that is colored yellow (not much time) and might have a long pathline to, say, your bedroom. Some activities will occur in the same space, of course, and this is exactly the kind of information that you want to record. When you have the boxes where you want them, paste them down on the sheet and draw your path lines.
4. Did this exercise give you any insight into your habits? Can you think of any ways that your behavior or your house could be more efficient? More enjoyable? Draw a new plan of your house based on what you learned about your activities and pathways within it.

Part 2: Home Away from Home
Have students research and report on artificial life support systems that have been designed, built or even just thought about. It could be the space station, or deep diving submarines, or experiments like Biosphere II. Have them diagram activities and pathways at the facility as they

did with their own homes. Discuss the different functions and systems in these facilities with the whole class.

Activities/Curriculum links:

http://www.noaa.gov/resource-collections/hands-on-science-activities
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https://sc.club.northwestern.edu/program/curriculum/