Branches on the Tree of Life Programs

ECHINODERMS

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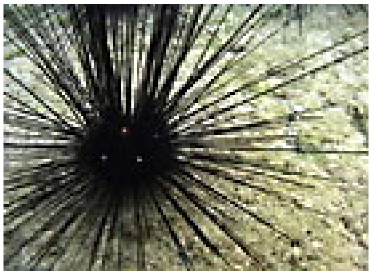
The Phylum Echinodermata consists of about 6,000 living species, all of which are marine. This video program compares the five major classes of living echinoderms in terms of basic functional biology, evolution and ecology using living examples, animations and a few fossil species. Detailed micro- and macro- photography reveal special adaptations of echinoderms and their larval biology.

(THUMBNAIL IMAGES IN THIS GUIDE ARE FROM THE VIDEO PROGRAM)

Summary of the Program:



The characteristics that distinguish Phylum Echinodermata are: radial symmetry, internal skeleton, and water-vascular system. Echinoderms appear to be quite different than other 'advanced' animal phyla, having radial (spokes of a wheel) symmetry as adults, rather than bilateral (worm-like) symmetry as in other triploblastic (three cell-layer) animals. Viewers of this program will observe that echinoderm radial symmetry is secondary; echinoderms begin as bilateral free-swimming larvae and become radial at the time of metamorphosis. Also, in one echinoderm group, the sea cucumbers, partial bilateral symmetry is retained in the adult stages – sea cucumbers are somewhat worm–like.

Echinoderms have an internal skeleton made of bony plates (ossicles) of calcium carbonate. They deposit this material after extracting dissolved calcium and carbonate (bicarbonate) ions from sea water. In some species, such as the sea urchin, plates of the skeleton are locked together to form a rigid structure. On the other hand, most sea stars and brittle stars can flex their 'arms', indicating that the skeleton has gaps and flexible plate junctures. Sea cucumbers have no real skeleton; only tiny remnant ossicles.

Many echinoderms have spines. In fact, the word 'Echinodermata' means 'spiny skinned'. The spines also are part of the internal skeleton and are covered by epidermis. It is usually a great surprise to students to learn that spines, such as the 40-centimeter long needle-like tropical urchin spines of Diadema, are actually internal structures.

Another phylum-level characteristic of echinoderms is the water vascular system, detailed in the section on Class Astroidea. The water vascular system functions primarily in movement, but oxygen exchange, and molecular nutrient uptake are also known functions of this system.

Class Asteroidea

Class Asteroidea, the sea stars, contains about 1700 living species of echinoderms. The name 'starfish', commonly used in the past, is being replaced by the name, 'sea stars', recognizing the lack of any close affinity of this group to fishes.

A dried sea star, with skin removed, shows a meshwork of bony plates and spines, creating the hardened endoskeleton. Holes in the endoskeleton reveal where projections of the body wall can be extended out into the sea water to function as oxygen and molecular exchange organs. These finger-like projections, the papillae, increase the surface area, improving gas exchange with the surrounding sea water.

Sea star movement involves hundreds of tube feet, small hollow tubes each tipped with a suction disc, and powered by the water vascular system. The intake to the water vascular system, the madreporite, is a stony sieve plate on the sea star's aboral surface. It acts as a screen to keep out detritus and parasites. Animation shows that the water vascular system has a central ring canal and connecting tubes running out into each ray.

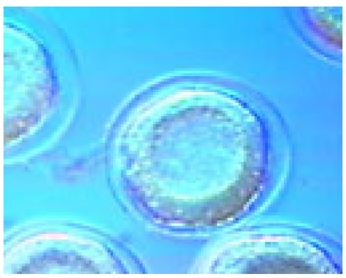
Each tube foot is connected to the radial canal and also to a balloon-like ampula. The muscular ampula works like a squeeze bulb, forcing water into the tube foot, causing it to straighten and extend. Biologists long thought that a suction disc at the end of each tube foot provided all the animal's holding power. However, recent investigations revealed that the tube foot can supplement its disc suction with a chemical cement that significantly increases holding power. Some sea stars, such as the Pacific Coast Pisaster ochraceus live in intertidal rocky habitats that experience phenomenal forces; equivalent to a wind blowing across the land at 1000 km/hour. Amazingly, the holding cement applied by the tube foot is 'reversible', through a biochemical process deployed by the sea star as it moves across the rock.

Although asteroids (and other echinoderms) have a relatively simple nervous system, lacking a 'brain', they have the ability to coordinate hundreds or even thousands of tube feet for directional movement. The Pacific Coast sunflower star, *Pycnopodia*, can have more than 40,000 tube feet. Sea stars have simple eye spots at the end of each arm, probably used for orientation to light. They use chemical reception to orient to food resources.

The ecology of the Pacific Coast common ochre star has been studied in detail. Having a water vascular system, it is relatively intolerant of exposure by low tides of the daily tidal cycles. Therefore, it generally lives lower down in the intertidal region, and moves upward during periods of high tide to feed on its preferred prey species, mussels and barnacles. (For a detailed visual treatment of this and other shore ecology topics, see our program, The Biology of Seashores.)

Sea stars feed by forcing their stomachs out of their bodies (eversion) onto, or into, the prey. Then they secrete powerful digestive enzymes to break down the prey in it's own body. Animation reveals that partially-digested nutrients are sucked back into the stomach region or they are brought in to the body through active transport. Once inside, nutrients are transported by ciliary action into digestive glands in each ray. The food molecules pass into the body fluid for distribution to the skin and other parts of the sea star's body. In most sea stars, undigested material is pushed out the oral opening, while some material is eliminated through a small anus located on the top (aboral) surface.

Also on top are five gonopores, openings where eggs or sperm are shed directly into the sea. Echinoderms are usually dioecious, male and female reproductive systems in separate individuals. Larval development goes through several stages on the way to becoming a baby sea star. After gastrulation, the larval series (including a bipinnaria larva) has bilateral symmetry, until metamorphosis, when the animal assumes the radial symmetry of the adult. Details of larval development are treated below in the section on Class Echinoidea.



Class Ophiuroidea

Class Ophiuroidea contains the brittle stars (also called serpent stars) and the basket stars. Ophiuroid means 'snake-like', referring to the form and motion of the arms. The arms of brittle stars are easily broken off, but will regenerate in a few days to weeks. Sea stars can also regenerate arms that are broken off, but for most species, the central region of the body must remain intact. Only a very few species, such as tropical species of *Linkia*, can actually regenerate an entire new body from a piece of arm that has broken off.

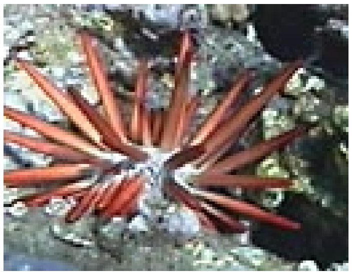
The tube feet of brittle stars are pointed, so this group does not use suction-mediated movement. The animal moves by using the arms in a kind of rowing stroke. The tube feet push materials aside, and also chemically detect food and move it to the mouth on the undersurface (oral side) of the disc. Brittle stars and basket stars are detritus-feeders and opportunistic scavengers. They usually collect small pieces of decaying matter that has fallen to the bottom or is drifting near the sea floor.

Ophiuroids are the most abundant class of echinoderms, with over 2000 species living in almost every ocean floor habitat. They have been dredged up from the deepest areas of the ocean.

Class Echinoidea

Class Echinoidea includes the sea urchins, heart urchins and sand dollars. The basic body-plan of this group involves a rigid endoskeleton, with a covering of outward-pointing spines. Sea urchins are generally more spherical, and the spines can vary from the extraordinary long and thin spines of tropical Diadema, to the stout spines of pencil urchins used for wedging into coral pockets, to intertidal species with flattened spines (for deflecting waves) to other species with short thin spines. One species of tropical urchin, *Toxopneusta*, has only a few spines but its surface is covered with another defensive structure – highly poisonous pedicellaria. (Poisoning from these pedicellaria has resulted in death for a few people who have handled or encountered these tropical urchins).

Urchin pedicellaria are three-jawed pincer claws (whereas those of Asteroids have two jaws). Pedicellaria seem to have two main functions - to discourage small larva from settling on the surface of an echinoderm, and for defense against predators. In response to an attack from a soft-bodied predator, (such as the Pacific sunflower star Pycnapodia), red, green, or purple sea urchins will move their spines aside, and deploy their multiple pedicellaria to pinch the predator. Usually, this will deter the soft-skinned predator.

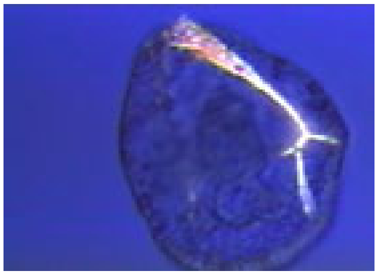


On the other hand, a hard-skinned predator, such as a large cancer crab, is relatively unaffected by pedicellaria. In cases of attack from these predators, the urchin will direct its spines (which can be aimed outward in any direction), toward the predator.

Urchins are primarily herbivores or detritus feeders, although some actively feed on attached animals such as sponges or sea squirts. A sea urchin's mouth is located on its underside. Inside the mouth is a unique jaw structure called the 'Aristotle's Lantern', here revealed through dissection. The structure is suspended inside the spherical endoskeleton (test) by a rigid frame that also provides attachment for muscles to control the biting and ripping functions of the jaws.

Looking at the urchin's test, one can see the rows of holes where the tube feet extend outward from the internal water vascular system, through the endoskeleton and out into the environment. In many urchin species, the tube feet can be extended outward to distances greater than the length of the spines. This allows the urchin to hold onto food that drifts against the spines, and move it to the mouth.

Sand dollar, heart urchins, and sea biscuits are echinoids where the endoskeleton is modified with various degrees of flattening. These represent adaptations for burrowing into different substrates - the highly flattened sand dollar lives in coarse sand, while the more bulbous heart urchin burrows in soft muds. In these cases, the animals have also retained a portion of the bilateral symmetry, and there is a forward end which leads the burrowing. These burrowing echinoids are detritus-feeders.



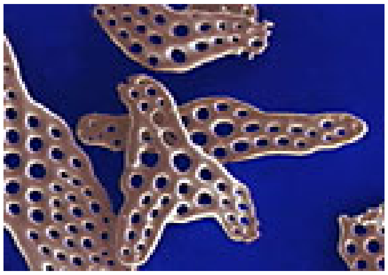
Sea urchin development is a well-studied process, and an excellent one for classroom observation. Gametes are produced by carefully injecting the fertile animals with potassium ion solutions. The eggs and sperm are collected in sea water, and the entire process of fertilization and development through larval stages can be observed through the microscope at intervals over several weeks. In this program, we show fertilization, blastula, gastrula, and several stages of larval development, using both normal microscope lighting and 'cross-polarized' microscope lighting to show the remarkable development of larval spines and their transformation at the time of metamorphosis. (We demonstrate some of these simply-deployed microscope techniques in our program The Light Microscope: Window on the Microcosm).

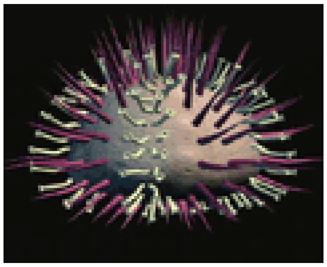
Class Holothuroidea

Class Holothuroidea is another group of common echinoderms, with over 900 species worldwide. Like brittle stars, these animals are detritivores, performing the important ecological function of 'mopping-up' the dead and decaying material that falls to the ocean floor.

The common name, sea cucumber, is particularly appropriate. Although few holuthuroids are green, many bear a strong resemblance to our garden cucumbers. The worm-like body suggests that they are bilateral creatures, not radially symmetrical; but their relationship to other echinoderms is shown clearly by an animation that transforms the horizontal sea cucumber body into the vertically-oriented body of the sea urchin.

All sea cucumbers have tube feet and a water vascular system (although highly modified). In many species, the three double-rows tube feet on the upper surface have been ‘lost’ through evolutionary adaptation. Sea cucumbers have also ‘lost’ the bulky endoskeleton prominent in other echinoderm groups. The skin is leathery, and remnants of the endoskeleton in the form of microscopic bony plates are embedded inside the skin tissue.





Sea cucumber defenses include powerful toxins secreted by the skin and toxic, and sticky tubes that shoot out the anus of some tropical species (tubules of Cuvier).

Class Crinoidea
Crinoids, commonly called feather stars, are mostly found in warm tropical seas where they attach to corals and other surfaces. Unlike other echinoderm groups, the crinoid’s mouth and anus are both on the top side of the animal, facing up, and they are surrounded by five sets of branching, tentacle-bearing arms that trap suspended detritus and plankton. When sufficiently disturbed, crinoids may swim by an awkward movement involving an alternating flapping of the arms.

Echinoderms evolved during the earliest proliferation of animal life, well over 510 million years ago. Fossil sea cucumbers have been found in the Burgess Shales, and fossil crinoids are common in sediments dated to Devonian times and older. The class Crinoidea obviously survived until present times, but other classes did not. Paleontologists recognize at least 17 extinct classes of echinoderms.


Review Questions - Echinoderms

1. What does the name “echinoderm” mean? Discuss how this name applies to the different classes of echinoderms.

2. Describe the function of an echinoderm tube foot.

3. When you find sea stars along a rocky coast at low tide, they are often clustered in crevices and under rock ledges. Why?

4. Explain two ways in which echinoderms are NOT radially symmetrical.

5. Do echinoderms see other organisms? If not, how do they find their food and avoid predators?

6. How do sea stars feed? How does this differ from sea urchins or sea cucumbers?

7. Which group(s) of echinoderms is (are) most likely to feed on plankton and suspended detritus?

8. Why do most echinoderms produce extremely large numbers of gametes?

9. What are the major differences between a sea star (or sea urchin) baby (larva) and the adult animal?

10. In addition to spines, what do sea urchins have for defense, and how are these used?

11. Describe differences between sea stars and brittle stars for: tube feet, body form, movement, feeding.

12. Sea cucumbers look like worms. How is their form related to radial symmetry and to the other echinoderm groups?

13. What happened to the endoskeleton in the sea cucumber line of evolution?

14. Describe two ways in which crinoids differ from sea stars.

16. Fossil evidence indicates that modern echinoderms probably evolved from an ancestor that lived over 500 million years ago. What characteristics would this ancestor have had?

15. Most major groups (phyla) of animals evolved in the ocean over 500 million years ago. Over time, many groups (phyla such as arthropods and molluscs) evolved to include species living in freshwater and on the land, but echinoderms are only found in the sea. Why are echinoderms still restricted to the sea?

17. Biologists believe that descendants of the first ancestral echinoderms include body plans quite different from modern living echinoderms. What is the evidence for this view?

Branches on the Tree of Life DVD - **ECHINODERMS**

Observations Section

Inquiry Approach: We recommend using the video observations ahead of the narrated program to generate interest and encourage speculation. Some discussion questions are listed below, although it may be sufficient to simply ask—What is it? or, What is going on? … and then let the discussion flow from there. Information related to the Observation sequences is provided in either the narrated program or the **Image Bank**, which contains over 120 echinoderm still images with descriptions. The image bank is on the DVD, but not the VHS version of Echinoderms.
Review: Using the observations for review, students can be encouraged to provide the narration.

Observation #1 Urchin Development
With the volume of sperm liberated into the water by male urchins, eggs must have some means of preventing fertilization by more than one sperm. How do they do it?

A day after fertilization a hollow ball of cells (blastula) has formed. The first sign of further development is a tube that has formed through the hollow ball of cells. How might that tube have formed? What might it become?

Three days later the larva has developed needle-like structures that shine out in polarized light. New folds of tissue can be seen out-pocketing from the gut. What might they become? Does this stage show radial symmetry like an adult echinoderm, or does it exhibit bilateral symmetry? Is there any indication of what these planktonic larvae are feeding on?

As the urchin develops over the next few days, more and more adult features can be seen. More crystalline structures show up brightly in polarized light. At what point does the larva appear to develop full radial symmetry? The last shot is of the juvenile urchin ready to settle and begin feeding on whatever it can scrape from the rocks. It has two different kinds of spines, long and pointed and, short and forked at the end. Which kind are on the mouth side?

Observation #2 Pedicellaria
Urchins and some seastars have little pincers called pedicellaria that have a defensive function. The demonstration shows how pedicellaria react to a bit tissue taken from a predatory sunflower star. Does it appear that the response requires touch, or are the pedicellaria able to respond to just the smell of sea star? Observing the response, do you think the pedicellaria respond independently, or is some form of coordination?

Observation #3 Urchin Dissection
A dissection shows some of the urchin's internal anatomy, but what are these structures? As in most animals, some are reproductive, others digestive, and some associated with feeding.

Observation #4 Juvenile Sea Star
What is it? What might be the function of the red spots?

Observation #5 Sea Cucumber and Sea Cucumber Dissection.
What is it? What might be the function of the branched tentacles? How are the branched tentacles controlled?