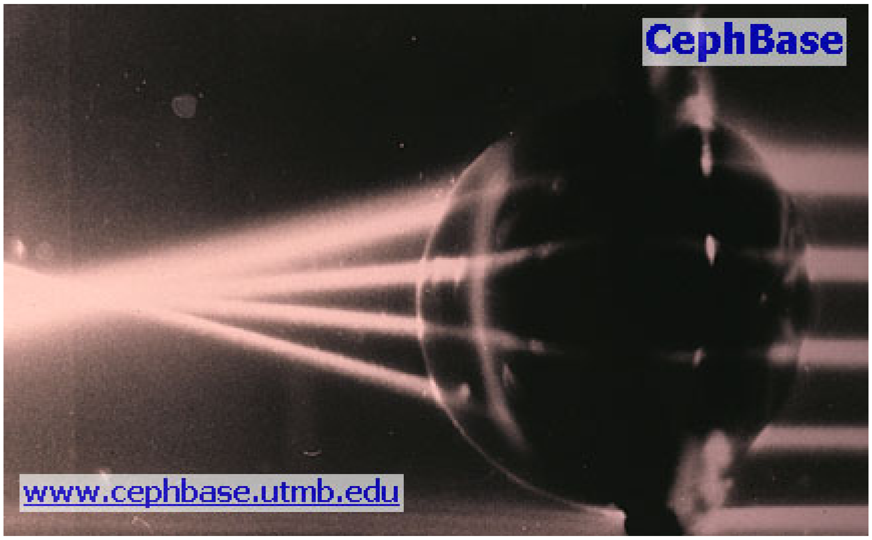
Introduction to: Cephalopod Vision

By Dr. James Wood and Kelsie Jackson

An Introduction to Vision in Cephalopods



(Figure 1: Four parallel light beams traveling from right to left are focused by a cephalopod eye. The point where the light beams intersect on the left is where the image would be focused on the animal's retina. Photo by John W. Forsythe.)

Cephalopods are known to have excellent senses and of these senses, their vision is perhaps the best studied. At a first glance cephalopod eyes look very similar to those of humans, whales and fishes. With the exception of the externally shelled and primitive nautilus, all cephalopods can perceive focused images, just like we can.

(Figure 2:The eye of a common cuttlefish, Sepia officinalis. Image by Dr. James B. Wood)

Cephalopods are invertebrates and other than being multicellular animals, they are not even closely related to vertebrates such as whales, humans and fish. Cephalopods, and their eyes, evolved independently. Why would animals so distantly related as a fish and a cephalopod have developed an eye that is so similar?

There are differences between vertebrate eyes and those of cephalopods. Perhaps the most surprising difference given the amazing ability of cephalopods to change color is that most cephalopods are completely color blind (Hanlon and Messenger 1996). How do we know? We can train octopuses to pick black objects over white objects, white objects over black objects, light grey objects over dark grey objects and vice versa but we can not train them to differentiate between colorful objects that look the same in grayscale (Hanlon and Messenger 1996). Also, most cephalopods only have one visual pigment. We have three.

Although many species have not yet been tested, the only cephalopod known so far to have color vision is the firefly squid (*Watasenia scintillans*). This species of midwater squid is bioluminescent and has three visual pigments (Seidou et al 1990). All other species tested so far only have one visual pigment.

Have you ever worn a pair of polarized sun glasses? Did you notice how they cut down the glare off of certain objects like cars on a sunny day or water? Fishermen often wear these glasses to help them reduce the glare reflecting off water so they can more easily spot fish. We have to put on a pair of special sunglasses to see differences caused by polarizing light.

Although most cephalopods can not see in color, Shashar N. and T.W. Cronin (1996) and Shashar et al (1996) demonstrated that octopuses and cuttlefish can detect differences in polarized light – without wearing polarized sunglasses. Shashar and Hanlon (1997) showed that squids *(Loligo pealei*) and Sepiolids (*Euprymna scolopes*) can exhibit polarized light patterns on their skin. Therefor cephalopods can not only see differences in polarized light, they can also create patterns using these differences on their bodies. We will discuss possible advantages of detecting differences in polarized light later on in this module.

Vision in Cephalopod Predators

The predators of cephalopods include fish, sharks (which are also fish but will be dealt with separately in this module) birds, marine mammals and other cephalopods (CephBase DataBase 2004). The visual abilities of all of these predators will be discussed here with the exception of cephalopods as they have already been discussed above.

All of the predators listed above have single lens eyes, although often there is some variation between them to make their eyes more suitable to their environment and behavior.

Fish

On land it is the air-cornea interface of vertebrates that gives most of the ability to focus. However, underwater, there is no such interface, so the lens must be much more powerful than that of terrestrial animals. The eye of the fish has a wide angle of view to make up for the fact that fish do not have necks and cannot turn their heads. Fish possess both rods and cones. Rods operate in low light intensity whereas cones allow for color and high light intensity conditions. Some fish also possess cones for vision in the ultraviolet part of the spectrum. Some fish have the ability to detect polarized light as do some cephalopods. There is large variation in eye morphology within fish as they inhabit a large number of habitats with varying light regimes, from complex coral reefs to the pitch black of the deep sea.

Sharks

Most sharks have excellent eye sight. Their eye structure is similar to our own and unlike other fish, the shark's pupils can dilate and contract to control the amount of light entering the eye. Sharks have both rods and cones which suggests some may have color vision; however, there are often more rods than cones to assist with vision in low light. Behind the retina is a specialized group of cells called the tapetum lucidum, which acts like a mirror to reflect light back at the retina a second time which further increases their visual abilities in low light environments. In fact, some species of shark can detect light that is up to ten times dimmer than that which humans can see. Some species of shark can see prey that is up to 70 to 100 ft. away.

Birds

The eyes of most birds have limited mobility as they are large and often tightly fitted in their skulls, yet the bird can make up for this by possessing a highly mobile neck. Most birds' eyes are mounted on the side of their heads, which gives them a large field of view but less binocular vision (the part of the visual field where the field of view from each eye overlaps). Some birds, such as hawks, have eyes directed further forward to increase the field of binocular vision which may help with targeting prey at high speed. Birds have rods and cones just as humans, but the ratio of the two changes depending on what time of day the bird needs accurate vision, i.e. when hunting. They also have 5 visual pigments, while humans only have three (red, green, blue) This means they have a greater sensitivity to color variation than humans. Some birds' eyes contain oil droplets which act like filters for different types of light. Seabirds often have red oil droplets which help to filter out blue light scattering from the surface of the ocean. This allows them to focus more clearly on objects at the surface.

Marine Mammals

Marine mammals that feed on cephalopods include dolphins, sea lions, and whales. Dolphins have a few adaptations to their eyes to assist them. For instance, they have muscles that can bend their lenses so they can focus above the water. They also have a tapetum lucidum for night vision. Dolphins have rods and cones like humans; however, it is still unknown whether they see in color. It is thought that their combination of rods and cones allows them to see a large range of light intensities rather than colors. Sea lions do not have color vision, although it is possible that they can detect light in the blue and green spectrum. They also have a tapetum lucidum for night vision. Sperm whales are known to feed on the infamous *Architeuthis,* or giant squid. These squid, however, live in the deep oceans where there is not enough light for vision to be effective. Researchers believe that the sperm whale does not have good eye sight, as its eyes are so disproportionately small to its head. It is thought that sperm whales use echolocation to find their prey.

The "Evolutionary Arms Race"

The evolutionary arms race is a theory that examines the evolution of two groups of organisms that interact. It explains how these separate groups remain competitive by adaptations that are related to each other. For example, plants develop toxins to ward off animals that wish to feed on them. In turn, animals that need such plants for survival may develop the ability to digest the plant matter without suffering the negative effects of the toxins. The plants develop more toxins and the animals develop more ways to avoid them or digest them. A medical example is humans and some bacteria. We develop antibiotics to kill them but some of them have evolved to become immune to the antibiotics. This is why doctors stress that you should always take all of your antibiotics. if even a few of the bacteria that are more resistant survive, they will go on to create a resistant strain.

These interactions can also be beneficial for both groups of organisms. For example, many flowering plants depend on insects to pollinate them. The insects benefit by receiving honey. The plant benefits by being able to pollinate its seeds. Many flowers have evolved to and bloom at specific times to attract specific species of insects.

The result is that organisms have enough defense mechanisms to avoid being eaten to extinction but not so many that its population exceeds the carrying capacity of its environment. In this case, an organism has found its environmental niche, an often specific set of environmental and biological conditions that allow its populations to remain stable over time. Animals that are unable to adapt to changing environments and predation pressures become extinct. However, it is important to remember that even though a balance has been achieved by which organisms fill their niches and do not appear to change, over a geological time scale, organisms are really still evolving. It's simply a very slow process, usually too slow for humans to see.

The evolution of cephalopods is thought to be due to an "arms race". Over the course of cephalopod history, they have moved from the sea floor, lost their shells, developed abilities to change color, shape and texture as well as the ability to communicate in complex ways. It was their capacity to adapt to changing pressures that ensured their survival as a family; those that did not adapt mostly became extinct. Here's a closer look at cephalopod evolution.

The first cephalopods appeared 500 mya, before bony fish existed. These first cephalopods had a hard external shell like many other mollusks but were able to leave the ocean bottom and swim to escape predators. When a predator came along, all the cephalopod had to do was let go of the bottom and float away like a hot air balloon. One of the first advances may have been the creation of multiple chambers connected by a siphuncle; this allowed these early cephalopods to slowly change their buoyancy. Other early advances were likely to have been the ability to swim slowly to control direction.

Two groups of cephalopods, the Nautiloids and Ammonids (570 mya), depended on their external shell and ability to swim to protect them from predators. Both of these sub-classes of cephalopods do not have many of the traits of their modern relatives, such as the ability to change color, to produce sharp images with a lens-based eye, or the ability to swim fast.

(Figure 3:The eye of Nautilus is simple and does not focus an image. Image by Dr. James B. Wood)

It is hard to say why the Ammonites and all but 6 species of Nautilus have become extinct. These cephalopods had a vide variety of external shells, some coiled, some long and straight, some with spines. These shells provided good protection from predators but inhibited the animals' mobility. Predation pressure has long been thought to be one of the major forces driving cephalopod evolution. Perhaps as species of bony fish, many of which swim much faster than an externally shelled cephalopod, appeared in the early oceans, armor just wasn't enough, and of those species that depended on armor, almost all have become extinct.

Modern cephalopods have evolved a different strategy. Instead of a heavy protective external shell, they have reduced and internalized this armor. The loss of the heavy armor frees them from the weight of carrying it around and the energy needed to produce it. Most modern cephalopods are active predators. Instead of heavy armor, they rely on speed and visual tricks to avoid being eaten. Some scientists have suggested that these adaptations were in response to pressure from predators. Indeed, many of the tricks such as the ability to change color, shape and texture as well as the ability to produce a visual ink decoy seem to be aimed directly at their predators. Fish, marine mammals, and birds all have evolved good vision.

Cephalopod Vision

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The Evolution of the Eye

It is known that nearly all living things including plants show some form of photosensitivity. How did this come to be? Firstly, most life, with the exception of some deep sea vent creatures, is affected by light emitted from the sun, whether they require it for survival or are sensitive to it and must hide from it. All such organisms need to possess some sort of organ that allows an organism to know whether it is in high or low light, and possibly from which direction the light is coming. The ability to detect light with and eye has been developing for more than 500 million years and includes a variety of possible forms ranging from simple photoreceptors in single celled organisms like *Euglena* to the highly complex vertebrate eye.

The first “eye”’ seen in single-celled organisms and flatworms were simple photoreceptors that could ascertain only the amount of light in the environment; the more advanced form of this was cup shaped, which allowed the animal to discern from which direction the light was coming. However, this sort of eye did not allow the organisms to see as we think of it; thus the pinhole eye developed. The pinhole eye is found in the *Nautilus* and consists of a small opening into a chamber which allows a very small amount of light through. Light will pass through the pinhole after bouncing off different points of an object, and in this way basic shapes can be interpreted, not in any detail however. The hole is so tiny only a small amount of light can get in which makes the image faint; if the hole were larger, the image would be distorted. This type of eye is incapable of focusing on objects at different distances. Instead, the size of the image produced will change in relation to the distance away from the object.

The compound eye was the first true image-forming eye which was thought to have formed some time during the Cambrian period, about 500 million years ago. The compound eye is common in insects and arthropods and consists of many ommatidia. Each ommatidia consists of a lens, crystalline cells, pigment cells and visual cells; the number of ommatidia will vary between species but may be up to 1000 per eye. Each ommatidia passes information on to the brain. This forms an image that is made of up dots, as if looking very close at a digital photo. A higher number of ommatidia mean more dots which make the image clearer. This type of eye is only useful over short distances; however, it is excellent for movement detection.

For an animal to be able to focus on objects at different distances or even to produce a clear image of its surroundings at all, its eyes needed to develop lenses. It is thought that early cup shaped eyes, like those of flatworms, contained a substance that protected them from seawater. If this substance were to bulge, it would form a pseudo lens that would help to make an image form more precisely, and this may be favored by the process of natural selection. Although the compound eye is full of lenses, the only way to make the image sharper with this design was to add more ommatidia. Of course, this means the eye would have to increase in size and can only do this to a point before it is too large for the animal. Thus, more complex lens eyes formed in both vertebrates and in cephalopods. Although both of these designs have many differences, there are also many similarities.

Cephalopod vs. Vertebrate Vision

As already stated, both cephalopods and vertebrates have very complex image-forming eyes with lenses. Both cephalopods and vertebrates have single lens eyes. They work by allowing light to enter through the pupil and be focused by the lens onto the photoreceptor cells of the retina. However, between the two groups of animals there are differences in the shape of the pupil, the way the lens changes focus for distance, the type of receptor cells that receive the light as well as some more subtle differences. In vertebrates the pupil is round, and it changes in diameter depending on the amount of light in the environment. This is important because too much light will distort the image, and too little light will be interpreted as a very faint image. The cephalopod pupil is square and adjusts for the level of light by changing from a square to a narrow rectangle. The way in which the two groups use the lens to focus differs. Vertebrates use muscles around the eye to change the shape of the lens, while cephalopods are able to manipulate their lens in or out to focus at different distances. The receptor cells of vertebrate eyes are rods and cones. The cones are used for vision in high light environments, while the rods are used in low light. The time of day the animal needs its vision to be most effective will dictate the ratio of rods to cones. Cephalopods, however, have receptor cells called rhabdomeres similar to those of other mollusks. These contain microvilli which allow the animal to see polarized and unpolarized light (see page on polarization vision). Lastly, the way in which light is directed at the retina differs between the two groups. Cephalopod retinas receive incoming light directly, while vertebrate retinas receive light that is bounced back from the back of the eye.

Convergent Evolution

Convergent evolution is occurs when animals that are not closely related have evolved similar characteristics. The formation of the single lens eye in vertebrates and cephalopods is an example of convergent evolution. The exact reasons why cephalopods and vertebrates have developed similar eye structures are not known. Some of the pressures they face in their environment, may provide some clues. For example, cephalopods (especially shallow water species) live in very complex environments, as do their vertebrate counterparts, fish. The cephalopod's primary defense mechanism is camouflage; without excellent vision this level of camouflage would not be possible. The prey of cephalopods is also the prey of numerous other species, so competition is high. Communication between cephalopods is thought to be primarily visual. Whether this developed because of a highly developed eye or whether the eye developed in response to a need to communicate visually is not known. Unlike their mollusk relatives who have defenses such as hard shells, cephalopods must be able to see predators coming to protect themselves through camouflage. In short, their environment and behavior is very much reliant upon their visual abilities, as are those of fish and marine mammals who separately developed these abilities.

Why these groups of animals that evolved from different ancestors undergo convergent evolution in respect to eye design? All the groups mentioned, including fish and cephalopods, live in environments with similar pressures. It may just be that there is only one general design for an effective eye that isn't too large and can facilitate all the necessary activities and abilities for species success and competitiveness in their given environments.

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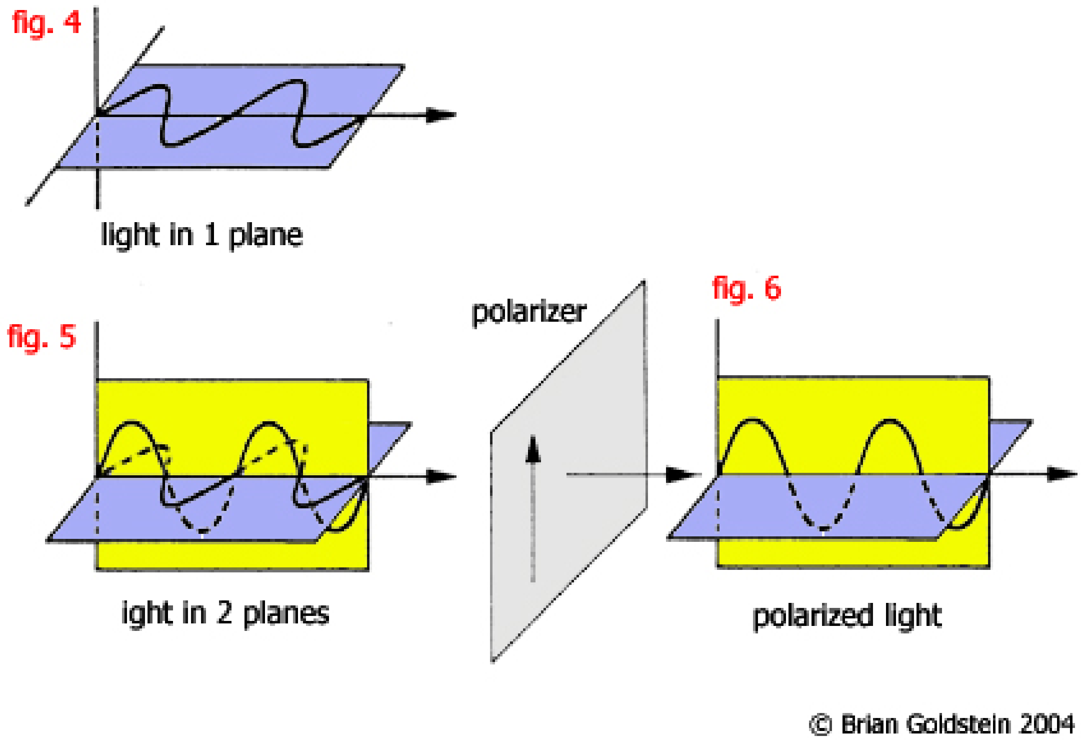
Seeing Polarized Light

It has been shown through scientific experiments that squid, octopus and cuttlefish are able to detect polarized light as well as create signals using polarized light on their skin (Shashar N. and T.W. Cronin 1996, Shashar et al 1996, Shashar and Hanlon 1997).

What is polarized light? How is polarized light different from unpolarized light? How does light become polarized? Why do some cephalopods see polarized light while other animals, including humans, can not? How do cephalopods use this to their advantage.

Light is a form of electromagnetic radiation which travels as a wave. The wave doesn't just vibrate on one plane; instead, it vibrates on many planes and in many directions at once while still traveling in the same general direction. Looking head on at a light wave, the assumption is that the wave is a straight vertical line as it moves toward the viewer. But, in actual fact, the wave moves vertically, horizontally, and diagonally all at the same time. This is how unpolarized light from the sun behaves, it is disorganized. Polarized light, on the other hand, only vibrates on one plane. The wave of polarized light, traveling toward the viewer appears as only one vertical or horizontal line



(Figure 4 show light traveling in one plane. However light travels in many planes. Figure 5 show light traveling in two planes that are 90 degrees (perpendicular) to each other. In Figure 6 a polarization filter is used to block all light waves except those traveling in the vertical plane. Custom figures created by Brian Goldstein.)

So then how does normal (unpolarized) light become polarized? This occurs through polarization and can happen in a number of ways. Firstly, when light hits an object, it can become polarized if it is reflected, refracted, or scattered of off certain surfaces. Light may reflect off a non metallic object or substance (like water) and become polarized. Polarized light that has experienced reflection will travel parallel to the surface of the object, which in the case of bodies of water creates glare. The amount of polarization will depend on the angle of the incoming light. When light undergoes refraction (i.e. it passes from one medium to another such as air to water and gets bent), it may become polarized, although this time the polarized wave will usually travel perpendicular to the surface of the substance it has passed through. Light may also become partially polarized by scattering as light waves bounce off particles while passing through a substance.

So why can cephalopods, and the majority of mobile marine animals (Cronin and Shashar 2001), see polarized light and humans can not? Cephalopods have different photoreceptor cells from humans. Cephalopods have photoreceptor cells that contain microvilli. The microvilli of each receptor cell are lined up parallel to each other. Microvilli contain the visual pigment rhodopsin, which is also orientated parallel in the microvilli. Receptor cells are aligned at right angles to each other, and hence the microvilli of one receptor cell will be at right angles to that of the next receptor cell. The rhodopsin assist in seeing the polarized light. Because the microvilli are arranged at right angles to one another, the animal is able to distinguish between different planes that the light is traveling on (Remember polarized light only travels on one plane).

Cephalopods can use their ability to see polarized light in many ways. Firstly, it is thought that they can see though the reflection created by silvery fish scales to better identify prey and predators (Cronin and Shashar 2001). Often this reflection is polarized. Just as humans put on polarized sunglasses to see through the glare created by polarized reflection off the surface of the ocean, the cephalopod can cut out the glare of polarized light produced by reflection off fish scales to better distinguish prey. Translucent prey may also be more visible for the same reason, as light reflecting off the tissues of the prey may be polarized, and while it may not produce glare, it would make the prey animal more visible to animals that can see this reflection such as cephalopods.

(Figure 7:The reds and blue-greens in this zebra display of a male Sepia pharoanis are created by iridophores. This is what we see. I wonder what would this pattern would look like to another cuttlefish? Photo by James B. Wood)

It has been shown that the iridophores on cuttlefish reflect polarized light in a way that they can intensify or shut off. This could be a form of communication between members of a species not visible to some other animals, especially predators (Shashar 1996). Predators of cephalopods include sharks, seals and cetaceans (CephBase). These are thought to not possess the ability to see polarized light, and thus cephalopods may have an advantage over them in being able to communicate with one another without attracting the attention of predators. It is also thought that cephalopods and other marine animals that can detect differences in polarized light may use their abilities to detect polarization to assist them in navigation (Cronin and Shashar 2001).

Cephalopod Vision – Teacher Resource

By Dr. James Wood, Kelsie Jackson, Brian Goldstein, Valerie Cournoyer, Roger E. Goss, Nancy W. Goss

Abstract

Cephalopods, like vertebrates, have evolved single lens eyes. Although this eye has much dissimilarity between the two groups of animals, they are functionally very similar. The fact that cephalopods and vertebrates have evolved such a similiar feature is quite amazing. This module explores cephalopod vision as well as vision of cephalopod predators. It introduces students to the mechanisms involved in cephalopod and vertebrate vision, while also considering the differences between the two groups. As the evolution of the eye is explored, the concept of an "evolutionary arms race" between cephalopods and their predators is raised. It also looks at the fascinating ability cephalopods have to see polarized light, and explores its uses in everyday life for cephalopods.

Objectives

The objectives of this module are to explore 1) how the eyes of cephalopods and their predators work and why both groups have developed similar eye structures 2) the concept of convergent evolution and the evolutionary arms race 3) how vision can enhance an organism's ability to compete in its environment.

Introduction

Cephalopods are known to have excellent senses. They move rapidly through their environment and use their senses to provide information about their surroundings. In some ways cephalopods are functionally more similar to fish than they are to other mollusks. Many of the predators of cephalopods, fish, marine mammals and marine birds (CephBase) are also mobile and have well developed senses. Of the senses of cephalopods, their vision is perhaps the best studied. At a first glance cephalopod eyes look very similar to those of humans, whales and fishes. With the exception of the externally shelled and primitive nautilus, all cephalopods can perceive focused images, just like we can.

This module compares and contrasts cephalopod and vertebrate eyes and discuses the concept of convergent evolution, the process where two distantly related taxa evolve similar structures. Cephalopod and vertebrate eyes are very similar in design and function but there are major differences between the two. Most cephalopods can not see in color while vertebrates can. However, cephalopods can detect differences in light polarization, something vertebrates can not do.

Key Concepts

- Cephalopods and vertebrates both possess similar eye structures.
- The similar eye structure of cephalopods and vertebrates is a prime example of convergent evolution.
- Cephalopods also have the ability to see polarized light, which may give them an advantage over some of their predators and prey.
- It is thought that predation pressure is a major contributing factor to cephalopod evolution and cephalopods and their vertebrate counterparts, fish, are engaged in an evolutionary arms race.

Student Learning Objectives

- To understand the evolution of the eye.
- To realize the similarities and differences between the cephalopod eye and the vertebrate eye.
- To investigate the concept of convergent evolution and understand how the similar eye structures of cephalopods and vertebrates is an example of this.
- To gain a basic understanding of what polarized light is, how it is formed, how cephalopods see it, and how they use this to their advantage.
- To explore and understand the concept of an evolutionary arms race and its effects on the evolution of a species.

Conclusion

Cephalopods have well developed senses including vision based on eyes that are amazingly similar to those of vertebrates. The concept of different animal groups independently evolving similar structures is called convergent evolution. Other examples of convergent evolution between fish and cephalopods is that members in both groups have evolved fins for locomotion and counter current gills to breath with.

Most cephalopods can not see in color although they can detect differences in polarized light. The ability to detect differences in polarized light may help cephalopods detect predators and prey; this gives them another way to visually discriminate objects in their environment, just as color does for us.

Many of the traits that cephalopods have evolved are thought to be in response from predation pressure from fish, marine mammals and marine birds. Indeed, cephalopods have many abilities such as changing color, texture and shape as well as ink decoys that appear to have evolved as a response to this pressure.

Web Resources & Bibliography

The physics of light and color

- Basic through to advanced lessons about light and color

http://science.howstuffworks.com/light.htm

Color and light in the ocean

- How color and light are affected by the ocean

http://www.soc.soton.ac.uk/JRD/SCHOOL/mt/mt001a.html

Cephalopods and color

- How cephalopods see and use polarized light

http://www.polarization.com/octopus/octopus.html

- Article about cephalopod color changes and camouflage

http://www.dal.ca/~ceph/TCP/chroma1.html

Bioluminescence

- Information about bioluminescence

http://www.seasky.org/monsters/sea7a3.html
http://www.lifesci.ucsb.edu/~biolum/

Animals and color

- Article about colors in reef fish

http://www.abc.net.au/catalyst/stories/s703938.htm

Deep sea creatures

- Information about many deep sea creatures

http://www.seasky.org/monsters/sea7a.html

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Shashar N. and R.T. Hanlon 1997. Squids (Loligo pealei and Euprymna scolopes) can exhibit polarized light patterns produced by their skin. Biological Bulletin. 193 (2) : pp.207-208

Shashar N. and T.W. Cronin 1996. Polarization contrast vision in Octopus. Journal of Experimental Biology. 199 : pp.999-1004

Shashar N., Rutledge P.S. and T.W. Cronin 1996. Polarization vision in cuttlefish- a concealed communication channel. Journal of Experimental Biology. 199 : pp.2077-2084

Vocabulary

Air-cornea interface: Contact zone between air and the surface of the eye (cornea).

Binocular vision: Vision using two eyes with overlapping fields of view, allowing good perception of depth

Carrying capacity: The number of people, or other living organism, or crops that a region can support without environmental degradation.

Convergent evolution: Coming closer together, especially in characteristics or ideas; relating to or denoting evolutionary convergence.

Environmental niche: A position or role taken by a kind of organism within its community. Such a position may be occupied by different organisms in different localities.

Iridophores: Cells that produce iridescent colors.

Photoreceptor cells: A structure in a living organism, esp. a sensory cell or sense organ that responds to light falling on it.

Photosensitivity: Having a chemical, electrical, or other response to light.

Polarization: Restricts the vibrations of a transverse wave, especially light, wholly or partially to one direction.

Microvilli: Each of a large number of minute projections from the surface of some cells.

Mya: Abbreviation for the term: millions of years ago.

Retina: A layer at the back of the eyeball containing cells that are sensitive to light and that trigger nerve impulses that pass via the optic nerve to the brain, where a visual image is formed.

Rhodopsin: A purplish-red light sensitive pigment present in retinas of humans and other animals.

Siphuncle: Calcareous tube containing living tissue running through all the shell chambers, serving to pump fluid out of vacant chambers in order to adjust buoyancy.

Tapetum lucidum: A reflective layer of the choroid in the eyes of many animals, causing them to shine in the dark.

Question
What animal has the biggest eye in the world?

Giant squid have the biggest eye of any animal. Their eye is the size of a dinner plate. For further information check out this site from the Smithsonian on the Giant Squid: http://seawifs.gsfc.nasa.gov/squid.html

Question
Why is vision so important in cephalopods?

Vision is important for many reasons. As cephalopods are able to rapidly move through their environment, they need to be able to sense where rocks, corals and the bottom of the ocean is so they don't smash into them and damage themselves. Also, vision is important for sensing predators. Finally, vision is important for communication as most of the communication between cephalopods is done with their color, shape and texture all of which are visual components of their appearance.

Frequently Asked Questions

Question
Are the colors we see the only types of electromagnetic radiation?

No, close to the red spectrum is infra red which we can not see and close to the blue end of the spectrum is ultra violet. These are close to the visible wavelengths that we can detect. There are many other types of electromagnetic radiation that we can not see such as radio waves, X-rays, etc. Check diagram. In fact, the wavelengths of EM we can detect are just a small range restricted to the visible spectrum. See figure in "How Cephalopods Change Color".

Question
What other interesting facts are there about squid eyes?

Some deep-water species have one eye that is larger than the other, for example *Histioteuthis* species do this in CephBase http://www.cephbase.utmb.edu/ image #577.

Materials and Activities

Methods

Students will use two polarized filters to conduct their activity in this module. These polarized filters can be ordered through scientific order houses such as Edmund Scientific or Frey Scientific Teaching Tools.

An alternate to the purchase of the polarized filters is to have students bring in old polarized sun glasses. Remove the lens from the glasses so that they can be manipulated for use in the activity.

Students will complete both data Tables and explain from this data how this type of vision could help a cephalopod avoid predation.

Answers to Student Activity on Polarized Light

Table 1: Polarized Filters

Position of Polarized Lenses	RATE: Amount of light that passes through both lenses Scale 1=least; 5=most
Lenses of same angle	5
one lens rotated 45°	3
One lens rotated 90°	0
One lens rotated 135°	3
One lens rotated 180°	5

Is there a point before 90° where the quantity of light drops off significantly? __Yes__

Table 2: Polarized Light and Glare

Items Viewed	Horizontally Polarized Light	Vertically Polarized Light
Car windshield	X	
Drops of water on lawn	X	
Windows of school building		X
Asphalt on the parking lot	X	
One other item with glare ( )		

Close one eye and look, and then close the other eye and look. Do things look the same or a bit different? Yes

Look through just one eye while turning the polarization filter. Which objects are affected and which are not? Water, windshield, glass were affected. The asphalt was not.

Analysis Questions Answers

1. How could vision like this help a squid trying to spot a shiny Tarpon (a fish) that could prey upon it?

   The light hitting the reflective scales of the Tarpon will be polarized differently from the surrounding light around the fish thus making it easier for the squid to see the Tarpon and make its escape.

2. Review the information in Table 1: Polarized Filters and Table 2: Polarized Light and Glare. What are your conclusions of how this type of vision could help a squid avoid predation?

   The cephalopod's ability to see polarized light may give it an advantage over its predators and prey. Because it is able to reduce the glare on objects in its environment, it can more readily distinguish those organisms which are about to prey upon it as well as increasing the likelihood of its ability to find the organisms it needs to prey upon for survival.

Student Activities: Cephalopod Vision

By Brian Goldstein, Valerie Cournoyer, Roger E. Goss, Nancy W. Goss, and Dr. James B.Wood

Activity

Students will observe objects through polarized lens in order to simulate the type of vision a cephalopod possesses.

Description

Students will complete two data tables—one which allows them to experiment with polarized filters and the other which helps them understand how light and glare are affected by polarized filters. Students will form conclusions from their data tables of how this form of vision could help cephalopods avoid predation.

Materials & Activities

- Two polarized filters
- Or an old pair of polarized sun glasses where the lens can be removed
- Pencils to record data on tables below

Procedure

1. Cut out two pieces of polarized material, or if using sunglasses, remove the lenses from old sun glasses.
2. Hold one section of polarized film or lens up to the sky. With the second piece of film in one hand, hold it in front of the first and slowly rotate it. Have a partner record how much light gets through.
3. Use Table 1: Polarized Light to record your date. Rate the amount of the light coming through on a scale of 1-5 with 1 being the least amount of light and 5 being the most amount of light.
4. How much light gets through when you hold both lenses or films at the same angle, one rotated 45 degrees, one rotated 90 degrees, one rotated 135 degrees, and one rotated 180 degrees.

Table 1: Polarized Filters

Position of Polarized Lenses	RATE: Amount of light that passes through both lenses Scale 1=least; 5=most
Lenses of same angle	
one lens rotated 45°	
One lens rotated 90°	
One lens rotated 135°	
One lens rotated 180°	

Is there a point before 90° where the quantity of light drops off significantly? ________

2. The film in one lens should be orientated 90 degrees to the film in the other lens (in this orientation if stacked o top of each other, they block all entering light.) This way one eye can see horizontally polarized light while the other eye can se vertically polarized light.

   Go out on a clear, sunny day and look at light reflecting off of the following: a car, windshield, drops of water on a lawn, windows in a school building, asphalt on the parking lot, and one other item with a lot of glare of your own choosing.

3 Use Table 2: Polarized Light and Glare to record your observations:

Table 2: Polarized Light and Glare

Items Viewed	Horizontally Polarized Light	Vertically Polarized Light
Car windshield		
Drops of water on lawn		
Windows of school building		
Asphalt on the parking lot		
One other item with glare ( )		

Close one eye and look, and then close the other eye and look. Do things look the same or a bit different? ________________

Look through just one eye while turning the polarization filter. Which objects are affected and which are not? ____

Analysis Questions

1. How could vision like this help a squid that is trying to spot a shiny Tarpon (a fish) that could prey upon it?

2. Review the information in Table 1: Polarized Filters and Table 2: Polarized Light and Glare. What are your conclusions of how this vision could help a squid avoid predation?

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