Color Change in Cephalopods

By Dr. James Wood and Kelsie Jackson

Introduction

Previous modules in this section have included cephalopod vision, how and why cephalopods change color, as well as light in the marine environment. Having studied previous modules, the reader will be familiar with how cephalopods view and interact in their environment, and how they use their awesome abilities of color change for practically every activity of their daily lives. This module is a graphic demonstration of color change in cephalopods. It will explore, using cephalopod photographs taken both in the laboratory and in the field, the different ways cephalopods use color change to interact with their own species, with other species, and with their environments. Cephalopods use their ability to change their appearance primarily for two things, camouflage and communication.

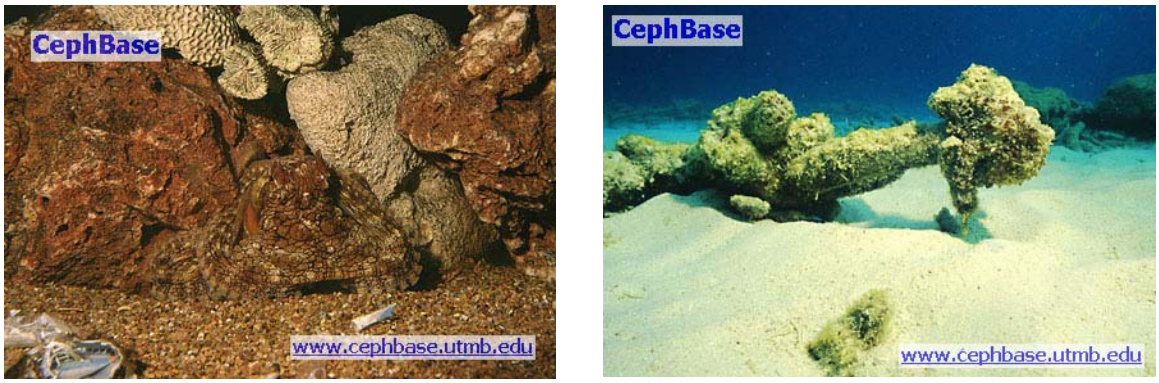
Many of the images used can be found on CephBase. In this module we included the CephBase image numbers as a reference.

Camouflage

It is hard to know for sure the first benefit that the adaptation of changing appearance had for cephalopods. The fossil record is spotty and does not provide many cluse as to behavioral adaptations. However, most scientists believe the initial benefit of the adaptation of changing appearance was crypsis, the ability to blend in with the environment. This allowed cephalopods to be camouflaged so they could more easily catch their prey. Perhaps even more importantly, camouflage was the first line of defense against predators.

Much of cephalopod evolution is thought to be driven by predator avoidance. The earliest of cephalopods are thought to have used the ability to leave the bottom and swim up into the water column as a way to escape predators. As both predators and their prey evolved, two major groups of cephalopods, the ammonites and nautilus, became some of the most common marine animals. These two groups relied on their external shell to protect them from predators. The ammonites are extinct, and there are now only six species of nautilus in existence. All the rest of the modern cephalopods, the coleoid cephalopods, have reduced and internalized shells and have the ability to change color, texture and shape to camouflage and avoid detection from predators.

(Figure 1: Image #873 by James B. Wood, the nautilus, Nautilus pompilius)

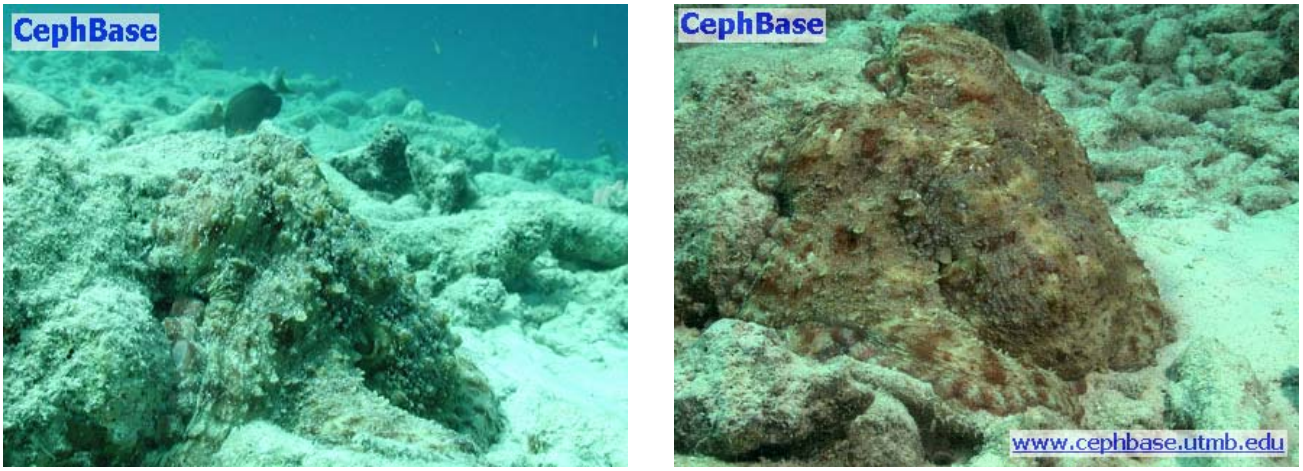


(Figure 2: Image #181 by John W. Forsythe and image #1407 by James B. Wood)

The above two images are examples of the California two-spot octopus, *Octopus bimaculatus,* and the common octopus, *Octopus vulagaris,* displaying their abilities to camouflage in different environments. This type of camouflage is known as background resemblance as both octopuses have adopted colors, textures and postures to attempt to blend into the background.

Octopuses are, of course, not the only cephalopods to display background resemblance. Below is an example of the cuttlefish, *Sepia pharaonis,* which is attempting to match the color and texture of the sand in its laboratory tank. Notice the white tipped papillae closest to the sand that give the appearance of small pebbles that can be seen in other areas of the tank. This ability not only protects the animal from predators, it also assists with hunting as prey can come quite close without realizing there is a hungry cephalopod nearby.

(Figure 3: Image #324 by John W. Forsythe)



(Figure 4: Image # 1510 and image # 1509 by James B. Wood)

The pictures above are of *Octopus vulgaris* camouflaged. The first photo was taken without the use of a flash, so the animal appears as it would to other animals in that environment. The second photo was taken with a flash, highlighting the red pigments that would not normally be visible in this light (for more information about light and color in the marine environment, visit the "Light, Color and Cephalopods" pages).

Background resemblance is not the only form of camouflage employed by cephalopods. Other methods include deceptive resemblance, disruptive patterning, and counter shading (Hanlon and Messenger 1996).

Deceptive resemblance is an attempt to appear similar to specific objects in the environment which is what these two Caribbean reef squid, *Sepioteuthis sepioidea*, (below) are doing. This is a common behavior seen in this species.

(Figure 5: Image #502 and #516 by John W. Forsythe)

(Figure 6: Image # 303 by John W. Forsythe)

This is an example of disruptive patterning being displayed by the cuttlefish, *Sepia pharaonis*. The large white band helps to break up the outline of the cuttlefish, making it harder to distinguish from a complex environment when viewed from above by predators.

(Figure 7: Image # 506 by John W. Forsythe)

A Caribbean reef squid, *Sepioteuthis sepioidea*, is showing counter shading. By having a dark colored top surface which slowly changes to a lighter colored under surface, the squid is less visible when viewed from above or below. When viewed from above, the darker dorsal surface matches the darker shades of the reef or dark blue open ocean below. When viewed from below, the light underside of the squid matches the lighter colored surface water above. When viewed laterally, as in the image #506 above, the dorsal side is too dark, and the ventral side is too light to camouflage from this angle. However Hanlon and Messenger (1996) suggest that even in this position, counter shading helps the animals hide as it causes the round mantel of the squid to appear flatter. This is particularly helpful for these squid as they spend most of their time in midwater.

In addition to being able to change color, texture and shape, modern cephalopods also use many behaviors to help keep them from being seen. For example, many species of cuttlefish and squid bury in the sand, such as *Euprymna scolopes*, the Hawaiian bobtail squid shown below (Anderson et al 2002).

(Figure 8: Image # 1534 by John W. Forsythe)

Additionally, many species, such as the Atlantic white-spotted octopus, *Octopus macropus*, shown below are nocturnal, making them less susceptible to predators that mostly hunt during the day.

(Figure 9: Image # 1400 by James B. Wood)

Different species of cephalopods vary significantly in their ability to change color, shape and texture. Hanlon and Messenger (1996) proposed that species that live in visually complex environments are more likely to have a wider range of patterns than those that live in less complex environments.

(Figure 10: Image # 1575 by John W. Forsythe)

The day octopus, *Octopus cyanea*, shown at left, lives on coral reefs and is day active. This species has a large repertoire of color, shape, and texture behaviors. Also, notice the goat fish in this image which commonly follow foraging octopus in the hope that fish and other prey may be flushed out of hiding.

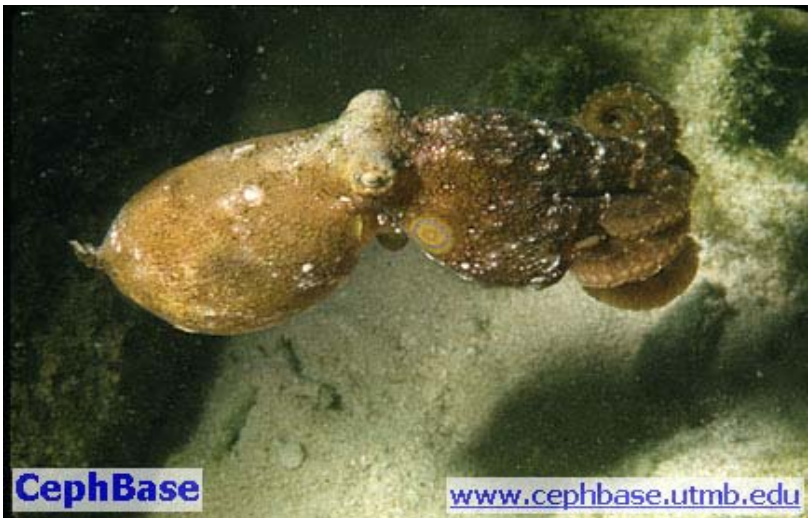
In contrast, the deep-sea octopus, *Bathypolypus arcticus*, lives in habitats where there is little to no sunlight (Wood et al 1998). They live on sandy and muddy substrates which are much less complex than a coral reef. This species has a very limited and poorly developed range of cryptic behaviors. Like many other deep-sea cephalopods, they don't even have an ink sac (Wood 2000). A visual decoy doesn't benefit them in an environment with no light.

(Figure 11: Image # 1411 by James B. Wood)

An even more startling behavior that some cephalopods use when crypsis fails is diematic behavior–shock tactics! These patterns are the exact opposite of crypsis. The animal uses highly visible color patterns and extends its arms and web to appear as large

as possible. Scientists think that these shock tactics are designed to cause predators to hesitate, for in those few seconds the cephalopod may be able to make an escape (Hanlon and Messenger 1996).

(Figure 13: Image # 1061 by John W. Forsythe)



(Figure 14: Image #0001 by Roger T. Hanlon)

Some species have occeli, or eye spots. These false eyes can either make the octopus appear as a bigger creature than it actually is or can misdirect a predator about where the head of the animal is located.

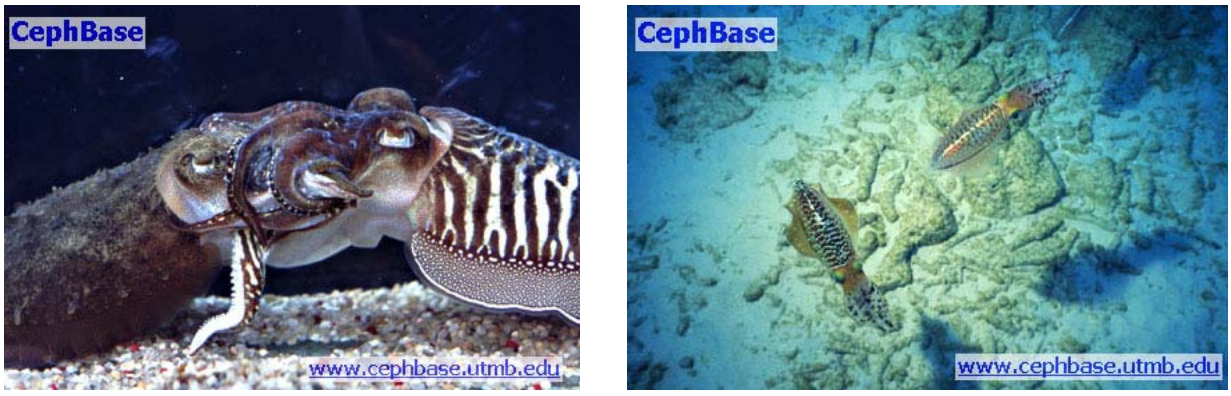
If the reader is still not able to find the octopus in the second picture (image #1407) at the start of this module, don't worry. *O. vulgaris* is showing complete camouflage and would be hard to spot even with a trained eye. The CephBase video library has an excellent example of an octopus in complete crypsis which then displays deimetic behavior when the photographer gets too close (#132 by Roger T. Hanlon, filmed in the Caribbean). What the viewer doesn't see is that only seconds later the octopus inks and jets away. This is often a cephalopod's last line of defense from attack and serves to further confuse potential predators while that animal makes a quick getaway. There are many methods of predator avoidance cephalopods use. It is important to remember that often a combination of these are used simultaneously depending on the situation.

Communication

Although the ability to change their appearance probably first evolved to avoid predators, this ability facilitated the development of other behavioral adaptations, such as the use of appearance to communicate with other members of their species and members of other species. Communication seems to be most developed in species of cephalopods that are found in groups (schools) or that aggregate in groups at spawning time. Cuttlefish and squid are good examples.

One of the most striking behaviors seen in many species of cuttlefish and squid is the zebra pattern. This high contrast pattern can be seen during acts of aggression in males. It is also commonly seen during courtship and is used to dissuade other males from attempting to mate with a particular female. As well as the contrasting light and dark shades, this display often involves certain body postures used in acts of aggression. The males may escalate to parallel swimming and pushing against each other. Often when this occurs, the displays usually will increase in intensity. However, only rarely, and in especially evenly match males, will this escalate to fighting.

This pattern is remarkably similar between different species, even between different orders such as squid and cuttlefish.



(Figure 15: Image # 1054 & 1423 by James B. Wood)

A particularly fascinating communication ability observed in some squid is double signaling. Excellent video footage of this behavior is shown in the nature documentary *Incredible Suckers*. In double signaling, a squid will send two messages at the same time. The most common example is of a male squid signaling one thing to the female squid he is courting with the half of his body that is closest to her, and signaling something else, often a zebra pattern, with the half of his body that is facing away from her. As his position relative to the female squid changes, so does the side these signals are on so that the zebra pattern is always away from her and towards other males.

(*Figure* 16: *This Caribbean Reef Squid is double signaling, one side of his body is white while the other side is brown. Image by James B. Wood)*

Schools of squid are thought to communicate in ways which are not yet very well understood (Mather pers comm.). The school of Caribbean reef squid, *Sepioteuthis sepioidea*, shown below quickly pales when threatened. Many species of squid are social and can be found in schools. It is still unknown to what degree they communicate with one another, but it is thought by some cephalopod researchers that schools such as this often have sentinels that keep watch and signal the others of impending danger.

(Figure 17: Image # 623 and image # 1420 by James B. Wood)

The uses of color change in cephalopods are numerous and complex; much more study still needs to be done on these fascinating creatures to help understand their incredible abilities.

To view these images in CephBase type in the following: http://www.cephbase.utmb.edu/imgdb/imgdb.cfm and go to the image library. Search for these images by looking for their image ID's. Search by species, photographer, or simply browse all the images of which there are over 1600.

Color Change in Cephalopods – Teachers Resource

By Dr. James Wood and Kelsie Jackson

Abstract

Cephalopods have amazing abilities to change color, texture and shape. Previous modules have explored how cephalopods change their appearance, and the ways they use this ability. This module presents images of cephalopods taken both in the field and in the laboratory to illustrate these abilities and show examples of situations where color change is used. The ability to change appearance is thought to have first evolved as a way to avoid predation and help cephalopods capture prey. In some species, especially squid and cuttlefish, this ability has taken on another role; it is used for communication. This module explores the main types of camouflage and communication and gives graphic examples of these. Group discussion questions are presented below in the student activity section.

Objectives

The objective of this module is to allow students to explore a graphically intense module about cephalopod color change to enhance their understanding of the uses of this ability.

Introduction

Previous modules have examined how and why cephalopods change color, as well as exploring some aspects of their environments such as changing light levels and spectra. This module is an excellent companion to these as it explores graphically the various uses of color change.

As described in “Why Cephalopods Change Color,” there are two main reasons for color change in cephalopods; these are camouflage and communication. However, there is certainly more than one method used in both of these cases. Camouflage in cephalopods can be used both for predator avoidance and to assist in hunting prey. Background resemblance, deceptive resemblance, counter shading and disruptive patterning are all methods used for camouflage. When this fails and the cephalopod is still threatened, it may use diematic behavior or shock tactics to give itself vital seconds to escape. As well as camouflage, many species have modified their behaviors to become less accessible to predators such as burying in the sand or becoming nocturnal. Communication wise, cephalopods have many uses for color change such as in courtship, acts of aggression, and warning other members of a social group of danger. All of these are explored in this module using images from the CephBase image library.

Often a cephalopod will use some combination of techniques in order to camouflage and communicate, which is one of the reasons this family is so complex. In comparison to their closest relatives, such as snails and oysters, they have developed amazing abilities that have enabled them to leave the sea floor and become competitive with their vertebrate counterparts, fish.

Key Concepts

- There are two main reasons for color change: camouflage and communication.
- There are several methods for obtaining color change including: background resemblance, deceptive resemblance, counter shading, and disruptive patterning.
- Behavior is also an important aspect of camouflage.
- During both communication and camouflage colors, as well as body postures and texture, are used. Often combinations of techniques are used for either communication or camouflage.
- A cephalopod's repertoire of patterns and postures may change depending on the complexity of its environment.

Student Learning Objectives

After studying this module students will:

- Be able to recognize and identify different techniques used for camouflage and communication in cephalopods.
- Have an understanding of how and why the ability to change color evolved in cephalopods
- Understand that an animal's environment is vital in determining its evolution and behavioral adaptations.
- Realize the complexity and uniqueness of cephalopods as invertebrates.
- Have a better understanding of what they have learned in previous modules.

Conclusion

Cephalopods use their ability to change color, shape and texture in their daily lives to avoid being detected by predators, to help them escape from predators that do detect them and to communicate both to other cephalopods and to other species. The CephBase image database contains over 1,600 images and is an excellent resource for studying the diversity of color patterns that cephalopods can produce.

Web Resources and Bibliography

- CephBase: This image library contains most of the images used in this module. It can be searched by species, image ID, photographer or key word for other images. CephBase also has information about many species of cephalopod, as well as information about researchers, articles and videos.
- http://www.cephbase.utmb.edu/

- An excellent book that fully explains all aspects of cephalopod color change and behavior. Hanlon, R.T. & Messenger, J.B. (1996) Cephalopod Behaviour. Cambridge University Press, UK.

- An excellent article by Alison King describing how cephalopods change color http://is.dal.ca/~ceph/TCP/chroma1.html

- The paper: Byrne R.A., Griebel U., Wood J.B. and Mather J.A. (2003) Squid say it with skin a graphical model for skin displays in Caribbean Reef Squid (Sepioteuthis sepioidea). Berliner Geowissenschaftliche Abhandlungen. 3: 29-35. is an excellent graphical example of communication in reef squid.

- The paper: Anderson R.C., Mather J.A. and C.W. Steel 2002. A burying behavior of the sepiolid squid Euprymna scolopes Berry, 1913 (Cephalopoda: Sepiolidae). Western Society of Malacologists Annual Report. 33 : pp.1-7

Color Change Vocabulary

- Camouflage: See crypsis

- Crypsis: A biological term for camouflage. There has been some argument over the difference between crypsis and camouflage. Some believe that the two terms are interchangeable while others do not. Often crypsis is used as a term that incorporates the behavioral aspects of concealment. Also it has been defined as concealment that does not require the use of materials from the environment. Using that definition, an animal that covers itself in leaves is camouflaged, while an animal that can change its own color, shape and texture to match its surroundings is undergoing crypsis. For our purposes the terms have been used interchangeably throughout the module.

- Background resemblance: Adoption of colors, textures, and postures to attempt to blend into the background so as to avoid predators.

- Papillae: Protrusion on the skin; minute projection on the skin.

- Deceptive resemblance: Attempt to appear similar to specific objects in the environment to avoid detection by predators

- Disruptive patterning: Attempt to break up the outline of an organism so as to make it harder to distinguish its true outline from a complex environment when viewed from above by predators.

- Nocturnal: Active during the night

- Deimatic behavior: Threat, startle, frighten or bluff

- Counter shading: Common color pattern of organisms in the water column that are dark-colored on top but light-colored on the bottom. This effect may be increased in some organisms by bioluminescent organs on the ventral surface. This coloration is used for camouflage in three dimensional space.

  Occeli: eye spots

Color Change
Frequently Asked Questions

Question
I was snorkeling and saw an octopus. I looked away for one second and it had seemingly disappeared. How was it able to disappear so fast?

You might be surprised if I told you that the octopus probably hadn't disappeared at all, but rather used one of its methods to conceal itself. For example, it might have traveled only five feet away but it might be using background resemblance to blend into its background. Believe it or not, octopus can even change their texture by creating papillae on their skin to resemble the background. They can also use a technique called disruptive patterning where they can break up the outline of their normal shape to make it appear totally different.

Question

Without changing texture color or shape, how could the Hawaiian bobtail squid conceal itself?

They have developed a way in which to bury themselves in the sand and thus avoid predation. When they are completely buried in sand, it doesn't matter what color, texture, or shape they are as their bodies are covered.

Materials and Activities

Below are some classroom discussion questions to further assist students in understanding cephalopod color change and the reasons for it as well as helping to develop critical thinking skills.

1) Question
Discuss why the high contrast zebra pattern used by many species of cephalopods is used for communicating to other members of the species. Hint, remember that cephalopods do not see in color.

Answer
The high contrast zebra pattern, composed of dark brown and white stripes is a very visible pattern in black and white. IE, you don't need to see in color to see this pattern.

Additional information
Since fighting over mates can be dangerous, it is beneficial to have a very clear signal of willingness and ability to fight. Smaller males can assess their rival and avoid becoming involved in a potentially dangerous fight that they are unlikely to win. By backing down they can save their strength and avoid being injured, live longer and grow bigger and stronger so that next time they might be the bigger and stronger animal.

2) Question
Do you agree that the ability to use color, shape and texture for camouflage probably evolved before these elements were used in communication?

Answer
This is an open ended question and any logical argument that the students present should be accepted. The truth is that we can't go back in time and know for sure.

Additional Information
Scientists believe that predation pressure largely shaped cephalopod evolution and most likely the ability to change appearance was an adaptation to cope with this pressure. Once the ability to change color, shape and texture existed, we believe that further adaptive uses for it, such as communication, evolved.

3) Question

If you were a hunted and tasty marine animal that had the ability to change color, shape and texture as well as the other tricks of cephalopods (ink, jetting, learning) how would you use these adaptations to: A) find food B) find a mate C) avoid being eaten

Answer
This also is a critical thinking open ended question. Again, anything logical should be accepted.

Additional information.
Cephalopods use their cryptic ability to avoid being detected by predators. When detected, they use diematic behavior, ink and jetting to escape. Many forage for food and mates at night when they are less likely to be seen. Some, like reef squid have elaborate courtship rituals. Scientists think that females especially use these rituals to insure that the male that they are with is healthy, strong and fit. During the day, most octopuses hide in lairs. Many squid live in schools which can protect them from predators but look out, squid can be cannibalistic!

4) Question

Dr. Wood and student intern Nancee are investigating which grey scale shades, from white to greys to black, octopuses can most closely match. Which shades do you think the octopuses do best at matching and why?

Answer
Again any logical answer with and explanation will develop students critical thinking skills.

Additional information
Our hypothesis was that the extreme shades, absolute white and absolute black would be hardest for the octopuses to match since they simply don’t have the physically ability to match these extreme shades. Also, these extremes don’t really exist in nature.

As for what we actually found, you will have to wait until we do more experiments and publish the results. We do have some interesting and surprising initial results.

Answers to Student Materials and Activities I

Question 1 Answer
The high contrast zebra pattern, composed of dark brown and white stripes is a very visible pattern in black and white, i.e., you don't need to see in color to see this pattern.

Additional information
Since fighting over mates can be dangerous, it is beneficial to have a very clear signal of willingness and ability to fight. Smaller males can assess their rival and avoid becoming involved in a potentially dangerous fight that they are unlikely to win. By backing down they can save their strength and avoid being injured, live longer and grow bigger and stronger so that next time they might be the bigger and stronger animal.

Question 2 Answer
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Additional Information
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Question 3 Answer
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Additional information.
Cephalopods use their cryptic ability to avoid being detected by predators. When detected, they use deimatic behavior, ink and jetting to escape. Many forage for food and mates at night when they are less likely to be seen. Some, like reef squid, have elaborate courtship rituals. Scientists think that females especially use these rituals to insure that the male that they are with is healthy, strong, and fit. During the day most octopus hide in lairs. Many squid live in schools which can protect them from predators, but look out, squid can be cannibalistic!

Question 4 Answer
Again any logical answer with an explanation will develop students' critical thinking skills.

Additional information: Our hypothesis was that the extreme shades, absolute white and absolute black would be hardest for the octopus to match since they simply don't have the physical ability to match these extreme shades. Also, these extremes don't really exist in nature.

As for what we actually found, you will have to wait until we do more experiments and publish the results. We do have some interesting and surprising initial results.

Answers to Student Materials and Activities II

Please note that the answers on the following chart are from Dr. Wood. Students may not be able to see all of the things that he saw – but it is important that they try.

	Video #69	Video #79	Video #16	Video #144	Video #59	Video #132
Observable Patterns: Teachers Edition						
Color	White and brown longitudinal stripes.	Brown and white zebra pattern.	Light brown or white.	Dark, hard to see as animal is under the sand.	White, brown, orange. Waves of brown on dorsal side of the animal.	Color change from camouflage (browns and greens) to white.
Texture	Smooth	Smooth	Medium texture (hard to see)	Can't see.	Bumpy	The animal changes texture from bumpy (textured) to smooth.
Body Position	Body held vertically near the end of soft corals.	Arms Splayed out at height of contest. Animals displaying their maximum size.	Hatching octopus is squeezing out of the egg.	Under the sand.	On top of sand. Courting male facing female.	The octopus increases his apparent body size as he turns white.
Movement	Hovering near the end of soft corals.	These male squid move close to each other and display to see who is stronger.	Hatching	Animals siphon blasts a hole in the sand and it digs in. Then it's arms start covering the remaining areas.	Male moves towards female and moves his arms up and down. Female moves away.	The octopus increases his body size and prepares to jet away as the camera continue to get closer.

Color Change Student Materials and Activities I

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1) Question
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2) Question
Do you agree that the ability to use color, shape and texture for camouflage probably evolved before these elements were used in communication?

3) Question

If you were a hunted and tasty marine animal that had the ability to change color, shape and texture as well as the other tricks of cephalopods (ink, jetting, learning), how would you use these adaptations to: A) find food B) find a mate C) avoid being eaten?

4) Question

Dr. Wood and student intern Nancee are investigating which grey scale shades, from white to shades of grey to black, octopus can most closely match. Which shades do you think the octopus do best at matching and why?

Student Activities: Color Change II

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

It is advised the Student Activities: Color Change I be completed as a class discussion before completing this activity.

Activity

Students will observe color changes, texture changes, and body position and movement in cephalopods using the CephBase website. From their observations they will draw conclusions.

Description

The CephBase website contains 144 videos of cephalopods and 1, 642 photographic images. Using selected video clips, students will view cephalopods to complete a data table.

Materials & Activities

- CephBase website, http://www.cephbase.utmb.edu/
- Color Change Observation page.

Procedure

1. Practice observation skills by viewing video clips of squid displayed from the CephBase website. Below are listed the video clips and a brief description. These clips may be viewed either on individual student computers or projected for the entire class to see:

Video clip #69
Group of four Caribbean Reef Squid (*Sepioteuthis sepioidea*) hiding amidst the branches of a soft coral. Each of the four squids is showing a body pattern or posture slightly different from the others. This vertical posture, often held for hours, is rarely seen in other species of squids.

Video clip #79
Two male Caribbean Reef Squid (*S. sepioidea*) in an agonistic Zebra bout for dominance; usually over access to female.

Video clip #16
We think this is the first ever video of a deep-sea octopus hatching. The footage is from Dr. Wood's PhD work. Pressure in the swollen egg pushes out the end of the mantle. Then the hatchling *Bathypolypus arcticus* frees itself from the egg, and a fully functional octopus emerges.

Video clip #144
Euprymna scolopes burying itself in sand. It uses water jets jets to blast up the sand which settles on the animal. The cephalopod also shovels sand on its back using its arms.

Video clip #59
Detailed view of body patterns and body postures of courting *Metasepia pfefferi*. The male is smaller and to the left at the start of this clip.

Video clip #132
Camouflaged octopus approaching coral with no sign of animal. As the camera gets closer, an *O. vulgaris* that was camouflaged, changes color to white and becomes visible.

2. Complete the Color Change Observation Page below:

	Video #69	Video #79	Video #16	Video #144	Video #59	Video #132
Observable Patterns: Teachers Edition						
Color						
Texture						
Body Position						
Movement						

Analysis Questions

1. Which video clips show cephalopods using camouflage?

2. Which cephalopod does not use color change to camouflage itself?

3. Which video clips show display behavior? i.e., to protect territory, to communicate with a potential mate?