NOVA Origins

Four-Part Television Series on PBS

Cladistics Cart

An interactive cart developed by the Pacific Science Center as part of the educational outreach materials accompanying the *NOVA Origins Four-Part Television Series on PBS*, airing September 28 and 29, 2004

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Welcome to *Cladistics Cart*

An interactive cart developed by the Pacific Science Center as part of the educational outreach materials accompanying the *NOVA Origins Four-Part Television Series on PBS*, airing September 28 and 29, 2004

The *Cladistics Cart* was developed to provide a hands-on introduction to one way scientists define the relatedness of life on our planet. Participants are led to use their own detailed observational skills on five related skulls to determine the skulls' evolutionary relationships.

Extensions to the main activity allow participants to make hypotheses of how certain physical adaptations benefited the organisms and what their probable lifestyle was.

Target audience: 2nd–8th graders, but enjoyable for ages six to adult.

Number of participants: This may be a one-on-one activity, or it may comfortably include up to five participants.

The *Cladistics Cart* has been successfully tested at community-center and after-school programs. It has been used in a science-museum setting as a stand alone portable activity cart. The components of the cart are designed to be easily portable in a small vehicle.

The *Cladistics Cart* may also be used in conjunction with the *It's Fossil Time* demonstration, also developed for the *NOVA Origins Four-Part Television Series on PBS*.

Concepts:

- Cladistics is the science of studying and classifying organisms according to their evolutionary relationships, through a comparison of the organisms' physical characteristics.
- Similarities among organisms are found in internal anatomical features and patterns of development that can be used to infer the degree of relatedness among organisms.
- Fossils can be compared to one another and to living organisms based on their similarities and differences. Some organisms that lived long ago are similar to existing organisms, but some are quite different. This helps scientists decide how animals evolved from prehistoric times. (While the actual "rules" of cladistics classifications are often the subject of intense scientific debate, this cart makes no attempt to impose a set of rules as facts to be learned. The cart does, however, attempt to show that groups of organisms can be sorted according

to characteristics within a group, and gives hands-on experience sorting fossils and fossil replicas into groups.)

Objectives:

Participants will:

1. use their observational skills to identify similarities and differences among a group of skulls.
2. determine skulls to be more similar to or less similar to other skulls based on various characteristics.
3. place skulls in order of relationship based on comparisons.
4. advanced participants will be able to hypothesize how certain physical adaptations benefited the organisms and what their probable lifestyle was.

Content Standard A: *Science as inquiry*

Participants develop an understanding about scientific inquiry by using their observational skills on five related skulls. The presenter will help them refine their observations by asking simple questions. Participants will sort the skulls based on similarities and differences. They will use these observations to form explanations about relationships between the skulls.

It's possible that different students may come up with different theories about the relatedness of the skills. This will allow participants to recognize and analyze alternative explanations and develop the ability to listen to and respect the skepticism of others, and to consider alternative explanations.

Content Standard C: *Life science*

Students develop an understanding of structure and function as living systems. Students will be shown that organisms on Earth have changed and adapted to their environment over time. This accounts for the diversity, relatedness and adaptations of organisms.

Students explore diversity and adaptations of organisms by comparing the five skulls. Although the different species might look dissimilar at first, the unity of the five species becomes apparent from analysis of their structure. Species acquire many of their unique characteristics through biological adaptation.

Two of the skulls are from extinct animals, one is from a critically endangered animal, two are from common animals. Extinction of a species occurs when the environment changes and the adaptive characteristics of a species are insufficient to allow its survival. Fossils indicate that many organisms that lived long ago are extinct.

Content Standard G: *History and nature of science*

Science is a human endeavor open to all races, genders and abilities. This cart will give a wide variety of participants a chance to make scientific observations and form hypotheses. Participants should be left with the feeling that the science underlying how scientists define the relatedness of species is based on extensive experimental and observational confirmation. While the main ideas are not likely to change greatly in the future, there is room for refinement in principle as new discoveries are made. Perhaps a member of the audience will be inspired to make some of those new discoveries.

A cart provides an opportunity for a participant to have a one-on-one interaction with a presenter. The presenter guides the participant's observations but does not dictate them. Each presentation of the cart will be unique, based on the participant's interactions. As such, there is no script.

Instead, we have provided an outline that shows the order in which concepts are typically best presented to the participant in order to guide his/her observations.

Following the outline is a list of extensions that may be used to address other interests expressed by participants or to extend the experience of particularly interested persons. Extensions are also wonderful attention-getters to draw new participants to the cart.

The outline and extensions are provided as an example of one way the information has been successfully presented. Your organization may have other resources that it would like to add. Consider this to be a guideline for evolving your own cart, specific to the needs and skills of your organization and audience.

A wide space has been intentionally left on the right side of the page for margin notes.

Materials

- ☐ Goose skull (natural)
- ☐ Archaeopteryx (cast)
- ☐ California condor (cast)
- ☐ Caiman (cast)
- ☐ Velociraptor (cast)

Optional extensions

- ☐ T-Rex tooth (cast)
- ☐ Archaeopteryx full-body fossil cast
- ☐ Drawings of the five animals
- ☐ Ammonite fossil
- ☐ Ammonite fossil cut and polished
- ☐ Nautilus shell
- ☐ Snail body picture
- ☐ Living nautilus picture
- ☐ Ammonite toy

Introduction

Cart is placed in full view of passing public. Top of cart in view has skulls of Archaeopteryx, Velociraptor, goose, caiman, California condor

Shelves of cart, unseen by public, hold full cast of Archaeopteryx fossil and drawings of Archaeopteryx, Velociraptor, goose, caiman and California condor

Presenter says that he/she has been given the task of sorting the skulls. He suggests that participant might help.

Identifying similarities and differences

Presenter starts by asking participant what all the skulls have in common. If necessary, presenter may provide suggestions to focus participant's observations, but should allow participant to be as self-guided as possible. Participant uses observational skills to note that all samples are skulls and all the skulls have eyes (orbits), nostril openings, other holes in the skulls, two-part jaw bones, etc.

Presenter then asks about common characteristics some skulls have that others do not. Again, the emphasis is on encouraging the participant to observe for him/herself. Characteristics that most participants notice are: teeth, beaks, placement of orbits (eyes), number of openings in skull, angle at which the spinal cord enters the brain cavity (last item usually requires some coaching), etc.

Sorting the skulls

The participant is asked to sort the skulls by their characteristics. Presenter allows participant to move skulls into groups and then into subgroups until a line of relationships is established. Possible subgroups include:

- Skulls with teeth and ones with beaks.
- Skulls with teeth sorted by shape of teeth or number of teeth.
- Beaked skulls sorted by shape of bones on palate.

Specific observations that should be mentioned are two-part lower jaw (a trait that all samples share), openings in skull, opening in palate, angle at which spinal cord enters braincase.

Skulls in each group continue to be compared and sorted until there is a progression. The following progression usually results: caiman, Velociraptor, Archaeopteryx, California condor, goose.

As participants continue to examine the skulls, they usually notice many more similarities between the skulls than they did at the beginning.

Have participants compare the characteristics of the two dinosaurs (Velociraptor and Archaeopteryx) to the bird and to the reptile, so they see that dinosaurs are more closely related to today's birds than to non-dinosaur reptiles.

Those participants who wish to continue may be presented with any of the following exercises, based on their interest and age appropriateness. Using these extensions will also allow a transition between different groups of participants.

- Younger kids can attempt to match drawings of the animals to the skulls.
- Older students may be asked to hypothesize why certain adaptations might be beneficial to that organism. For example, why would it be beneficial for a goose to have thinner bones than an Archaeopteryx or for a goose to have a secondary palate, unlike a condor? Questions about benefits should be made using the characteristics the participant mentioned.
- Present Archaeopteryx fossil cast. Have participant point out the characteristics most commonly thought of with dinosaurs (e.g. claws on “hands”, long tail, teeth) and those traits commonly thought of with birds (e.g. feathers, extended bones for wings).
- Participants may be presented with a fossil Ammonite that has been cut in half to expose the inside chambers. They compare this structure to a snail and to a chambered nautilus. The conclusion is that the Ammonite is more similar to the chambered nautilus. They are then shown a picture of a living chambered nautilus, a cephalopod closely related to a squid. They can then hypothesize on the form of the Ammonite body.

Unfortunately, we haven't invented a time machine. Until we do, we don't have a firsthand way to see the progression of life from single-celled bacteria to space-faring humans. Yet, life as we know it shares the same basic DNA blueprints. All life on this planet is related.

This relatedness is apparent with living organisms. DNA analysis shows approximately 98 percent DNA match of humans to chimpanzees. It also shows about 50 percent genetic match between humans and a banana. It's not surprising that we share DNA with chimpanzees, because we look more alike than not—we have physical attributes in common. There are, of course, physical attributes that we don't share with chimpanzees. A detailed analysis of the traits will give us a result that is pretty similar to the DNA comparison. That a human has about a 50 percent DNA match to a banana may not be obvious, but it shows the fundamental nature of the DNA building blocks shared by all life on Earth, and that, while limited in number, these building blocks can combine to form a nearly unlimited variety of organisms.

Cladistics is much more than comparing how organisms look. Species may look similar because they have evolved traits to fit a similar ecological niche even though they are not closely related. For instance, bats and birds both fly. They have both evolved traits that let them exploit resources in the air, but a bat is more closely related to a hippo than to a bird.

Cladistics comes from the Greek word, "klados" which literally means small branch or twig. Cladistics may be thought of as working out life's family tree. It assumes that all of life is related and the adaptive differences may be traced back to a common root by tracing at what point and in what order those changes happened.

The key to the cladistics process is the careful observation and comparison of specimens. How bones in the skull are arranged, inner ear structure, wrists, ankles and other bone structure are keystones to cladistics.

A major challenge in using cladistics with fossils is the way in which fossils form. Fossils give us very little information about the soft parts of ancient animals. We know Velociraptor had sharp teeth, but we don't know the color of its skin. Animals such as jelly fish and worms that don't have bones or other hard parts rarely leave traces of their existence at all. We have thousands of examples of Ammonite shells, but no direct evidence of how the soft parts of their bodies appeared. When we attempt to learn about ancient extinct organisms, we are usually limited to the parts of those organisms that could leave a fossil.

There are many ways in which fossil may form, but here are a few general rules, which explain why we have little fossil evidence from the soft parts of ancient organisms.

Protection from rot: When a plant or animal dies, it will typically rot away quickly. For this not to happen, the organism must be buried quickly in an environment where its remains are not exposed to oxygen. The most common way is for an organism to be buried under sediment in water. As layers of sediment pile on top of the organism, the sediment turns into sedimentary rock. This is why we have a far more complete fossil record for marine animals than for land animals. Some other materials in which an organism may be preserved include tar, sap, desert sand or ice. Perhaps our Velociraptor was caught in a flash flood and quickly buried under tons of sediment.

Even in sedimentary rock, the organic material will eventually rot away and become parts of something else. In some cases, the organic material has been replaced by minerals. Imagine water trickling through the sedimentary rock. Minerals dissolved in the water may be deposited in the pores of the Velociraptor skull. As the organic material of the skull dissolves, the shape of the skull is still maintained by the minerals deposited there. This process, called permineralization, is one of the ways that fossil evidence may be left even after the organic material from the organism is gone. Other methods include casts/molds, replacement, or carbonization.

Unchanging location over time: Now we have minerals in sedimentary rock in the shape of Velociraptor's skull. These minerals must be in a place that is relatively free from change. Should these minerals become buried under too many layers of rock, the rock itself might change its structure (metamorphic rock) and destroy the evidence of Velociraptor's existence. Should layers erode, the minerals recording the shape of Velociraptor may be scattered and become parts of other rocks. Either way, our clues to the existence of Velociraptor would be lost.

Exposed in the present time: Even if our Velociraptor died and was buried under the right conditions, and happened to be in an area where mineral-laden water replaced his bones with minerals before completely eroding his skull, and this happened in an area where the rock didn't drastically change for 70 million years, we still have very little chance of finding him. The layer of sediment where he was buried would have to be exposed for us to find him. Beyond this, the incompleteness of the fossil record means that the chance is very small of finding a fossil of an organism that was the direct ancestor of another fossil we happen to find. Think of the millions of fossils still buried in the earth. Clues to life that once existed are waiting to be discovered—or destroyed. Perhaps one of the participants will go on to discover one of the missing pieces in the puzzle of life on Earth.

Cladistics is a powerful, and relatively new (50 years old or so), method for determining the evolutionary histories of organisms, and representing those relationships in tree-like diagrams. But in these family trees, the ancestor is shown at the bottom, not the top. A cladistic family tree (called a cladogram) doesn't attempt to describe ancestors; instead, it shows points at which lineages diverge from a common ancestral form, based on analyzing evolutionary changes in the traits of organisms.

Fossils and replicas may be purchased from:

Skulls Unlimited
10313 Sunnyland Rd.
Oklahoma City, OK 71360
1 (800) 659-Skull
http://skullsunlimited.com/

Two Guys Fossils
1 Lynnes Way
East Bridgewater
MA 02333
1 (800) 367-7457
http://www.twoguysfossils.com

Wards Natural Science
PO Box 92912
Rochester, NY
1 692-9012
1 (800) 962-266
http://wardsci.com

Web sites

http://www.amnh.org/exhibitions/Fossil_Halls/cladistics.html

http://www.pbs.org/wgbh/nova/teachers/activities/2905_link.html

http://www.ucmp.berkeley.edu/clad/clad1.html

Books

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Niles Eldridge and Joel Cracraft. 1980. *Phylogenetic Patterns and the Evolutionary Process.* Columbia University Press, New York, USA.

Paul H. Harvey and Mark D. Pagel. 1991. *The Comparative Method in Evolutionary Biology*. Oxford University Press, Oxford & New York.

Wayne P. Maddison and David R. Maddison. 1992. *MacClade: Analysis of phylogeny and character evolution.* Version 3.0. Sinauer Associates, Sunderland, Massachusetts, USA.

D. L. Swofford. 1991. *Phylogenetic Analysis Using Parsimony (PAUP), version 3.0s.* Illinois Natural History Survey, Champaign, Illinois, USA.

E. O. Wiley, D. Siegel-Causey, D. R. Brooks, & V. A. Funk. 1991. *The Compleat Cladist: a primer of phylogenetic procedures.* Univ. of Kansas Museum of Natural History, Spec. Pub. No. 19.

Natural history of specimens used in cart

California condor (Gymnogyps california)

http://www.npca.org/wildlife_protection/wildlife_facts/condor.asp

http://animaldiversity.ummz.umich.edu/site/accounts/information/Gymnogyps_californianus.html

Caiman (Paleosuchus trigonatus)

http://animaldiversity.ummz.umich.edu/site/accounts/information/Paleosuchus_trigonatus.html

Archaeopteryx (Archaeopteryx lithographica)

http://www.ucmp.berkeley.edu/diapsids/birds/archaeopteryx.html

Goose (Branta canadensis)

http://animaldiversity.ummz.umich.edu/site/accounts/information/Branta_canadensis.html

Vecociraptor (Velociraptor mongoliensis)

http://www.seismosaur.com/Case16.html