**Lesson Ideas to Accompany Chapter 9 of *Do Elephants Have Knees?***

**The Saga of Mooshmael**

*Reflection: Mooshmael's Inheritance*

Mooshmael's voyage on the *Artiodactyl* introduced the story of his inheritance shared with Doris. The story depends upon humor and whimsy to suggest the basis for arguing the surprising evolutionary affinity between whales and limbed creatures. Which images in the story are easiest to remember? In what ways do they help to make the evolution of whales make sense? What features are crucial to establishing relationships among ancestral whales and to living mammals?

Mooshmael seems to have quite a diverse set of relatives. In what sense do they represent forms that are intermediate between land (or edge of the sea) and ocean creatures?

Perhaps the most striking difference between moose (and the hoofed stock closely related to moose) and whales is what they eat. Moose munch plants; whales ingest animals (fish, squid, shrimp—snagged by teeth and ensnared by baleen). That switch is as remarkable as the change from hindlimbs to flattened tail flukes (flukes are *not* modified limbs, by the way) and from forelimbs into flippers (flippers *are* modified forelimbs). Oily skull chambers, unusual ears, and blowholes truly disguise a whale's inner moose (or hippo or *Ambulocetus*). What does the story make you wonder about? What would you like to know more about?

Imagine you could interview each of Mooshmael's aunts, uncles, and cousins about their lives. What would you ask each one?

In Bernard Wiseman's *Morris the Moose*, the cow explains that she is a cow because her mother was a cow. Morris cogently reasons that a cow's mother must be a moose because the daughter, in his mind, is a moose. Is one or the other being more logical? How would you resolve this conundrum?

Mooshmael applies this same style of reasoning across multiple generations. If your ancestors were moose, then you (Doris), their direct descendent are a moose. Mooshmael seems to have carried Morris' logic too far. At some point modifications of body and limb (and tail, skull, organs, blubber, ears, and teeth) generated such novelty that a new life form came into being: whales. Where does one draw the line between non-whales and first whales? Is the line real or imaginary? Who's to say? Is it quite true or simply whimsical to claim that whales once *walked* the earth?

Is a whale a fish? Herman Melville defined a whale "a spouting fish with a horizontal tale."

*Discussion: Moose Logic*

"Moose Logic" sets up an analogy between the Morris the Moose's reasoning and the classification of creatures ancestral to whales. Is a moose is a deer with a bulbous snout, or is a deer is a moose with a skinny snout? Both have snouts and antlers, features likely shared with a common ancestor. On the other hand, horses and moose both have bulbous snouts. In that respect, they both differ

from deer. Maybe a horse is a kind of moose without antlers and a moose is horse unable to whinny.

From Morris' perspective, what makes a moose a moose? In other words, what features define a moose? Must a moose have all of these features, at least some of these features, or most of them? Is there a single feature that all moose must possess? What are some characteristics of moose that just happen to be but are not special to moose?

Just as the set of features that define a group of animals varies, so, too, may each feature vary. When is an antler no longer an antler? What makes a horn a horn and not an antler? Which one tends to grow in a spiral shape, a horn or an antler? Which one might you see covered in skin and fur ("velvet") and which one is made of keratin, the same material found in fingernails and hooves?

*Exercise: Creature Features and Ancestry Trees*

Horse, deer, cow, moose: which two are most similar to each other—more similar to each other than either is to the other two animals? Sorting out relationships as indicators of shared ancestry can be challenging, but also a playful exercise. Try to imagine recent and distant common ancestors. "Moose logic" helps to do so.

Part I: Nesting Groups with Loops

Start solving the puzzle of common ancestry by writing the names of the pair creatures (or perhaps a triplet of creatures) imagined to be most similar to each other based on an essential feature (or small number of features). Draw a loop around them. Next to this shape, write the name of one (or perhaps another pair) of few remaining animals. This one (or small group of two or three) is the most similar to the first pair in some important way. What features does it share with the first group? What feature or features does it lack?

Draw another loop around the new set. Now, in line with the two looped groups, add the name of the next and perhaps very different creature. Draw a third loop that encloses all of them. Listing and looping can go on and on. It's best to practice with a small number. Do additional creatures belong in the existing loops or require new ones? New loops can be nested within existing ones or placed next to them. For example, add a rhino. Rhinos have horns, but not on the side of the head. They do not walk on two toes, as do cows, deer, and moose. Where do they belong, according to "moose logic"?

It's OK to disagree about which features to use in arranging groups. The goal is to be logical in sorting and then use the sorting to make guesses about recent and distant ancestry. Deciding which features work best for this exercise depends upon knowledge of anatomy, inheritance, and genetics. Start the task at any level of understanding—then revise solutions based on new knowledge. Think about the thinking—and additional information—helpful to improving the solution to the puzzle.

Grouping and looping complete part one of the exercise. The outcome is a set of nested categories. The second task is to imagine ancestors shared and not shared by the members of these categories and represent them in a branching tree diagram.

Part II: Imagining Ancestry Trees

Imagine an ancestor held in common by both animals in the first pair circled. Call this creature a "Floomp." Now imagine a creature that shares a feature (or features) with the first pair and the next-most similar animal. Call this creature a "Blorf." Finally, imagine a creature that has the feature (or features) shared by all. Call this one a "Dirgot." If solving the puzzle requires inventing a couple more silly creature categories, that's fine. Feel free to redo any part of the puzzle (groupings, branchings, namings) at any stage.

The solution tree is not a fact: the solution is a plausible story of descent. The facts are the presence or absence of key features among creatures. Of course, since even features vary, there always remains room for interpretation and revision. Enjoy the challenge and be comfortable with multiple, competing answers!

The goal in part two of this exercise is to make a branching diagram suggesting the possible descent of deer, cows, moose, horses, and maybe even rhinos. Draw this branching diagram below the names arranged in a row and nested in loops. The diagram begins well below the list of creatures and starts with Dirgots. One branch extends from Dirgots to Blorfs. Another branch extends from Dirgots to the creature (or creatures) not included among the Blorfs.

Two branches extend from Blorfs. One connects to Floomps, the other to the creatures grouped in the next-to-outermost circle. That is, to the group of Floomps plus the other animals with legs (horses in the example). Floomps then branches to the two innermost creatures sorted by head adornment.

There are usually different ways to draw such diagrams. How they branch depends upon which features are considered the most important ones inherited from a common ancestor. In this exercise, Floomps stand for the most recent common ancestor, Blorfs for a more distant one, and Dirgots for the most ancient ancestor of all. Dirgots share something quite important with all of the subsequent groups. Floomps share something in common with their descendants. Sometimes, a cluster of traits, not a single feature, guides making branching decisions. The finished diagram is a "tree" of likely ancestry. It suggests what kinds of creatures might have existed in the past given the variation observed among a set of animals in the present.

Finding a "primitive" creature—one thought to be a likely precursor to later ones with similar features in modified form—sets drawing the tree forward in time rather than working backwards. Puzzling out whale ancestry works in both directions: backwards from living creatures increasingly dissimilar from each other and forward from fossils having traits suggestive of ancestor status.

Mooshmael thought about his ancestors and relatives in both senses. His family photo album held images of fossil whales and protowhales and he carried on a conversation with Doris, a living whale, about features shared by limbed-"whales" and close relatives of moose (even-toed ungulates, hippos). The cast of ancestral characters included t Uncle Basil (a *Bailosaurus*), Aunt Rodhi (a *Rodhocetus*), Cousin Amble (an *Ambulocetus*), Great Uncle Pakky (a *Pakicetus*), Great Antie Indo (an *Indohyus*). Doris counted Helene, a toothless baleen whale, among her living relatives.

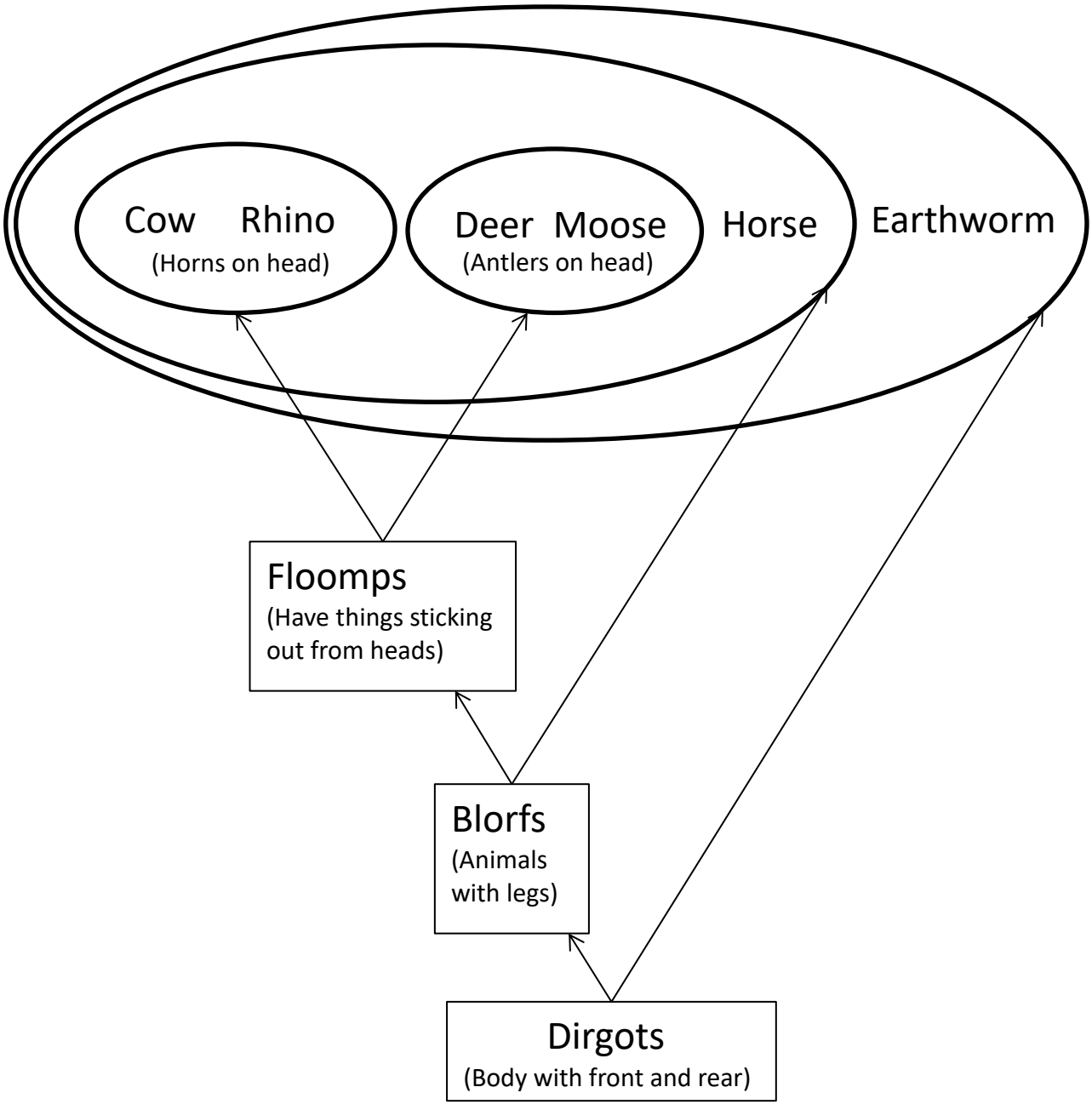
All of these creatures (with one caveat) sported enameled teeth. Baleen whales develop then reabsorb enameled teeth early in life. (Chapter 9 describes the fossil baleen whale, *Aitiocetus weltonni*, an intermediate between toothed and baleen whales). Hindlimbs disappear in modern whales, but Uncle Basil had tiny ones. Aunt Rodhi swam, but hat powerful hindlimbs—and an ankle bone very similar to one always present in living and fossil even-toed ungulates, the Artiodactyls (after whom Mooshmael named his ship). Neither Basil nor Rodhi had a fluke like Doris and Helene.

Cousin Amble had a hoof-like toe. In a very real sense, the more ancient the whale ancestor the more moose-like the limbs. Building a tree of ancestry uniting hoofed stock with fluked creatures switches from limbs to teeth at one point and to skull and ear structures at another in the work of professional paleontologists. In Mooshmael's story, "high crowned premolars" clinches the inference of close relationship between modern Doris and ancient aunt Indo.

The adventurous might wish to draw ancestry trees suggesting the degree of shared inheritance among hoofed creatures and cetaceans, modern and fossil. Work as before: arrange the names in a row, first with a pair (or very small set) quite similar to each other—each more similar to the others in this first set than any is to any other creatures under consideration. Keep on grouping and looping with the sorting criteria explicitly in mind. Using more than one criterion at a time is certainly permissible. Don't be too shy to look up anatomical information on-line in *Wikipedia* to resolve confusing branching points. And remember, the goal is a plausible solution to the puzzle of descent with modification—a solution that is logically consistent and grounded in an interpretation of anatomical evidence. Debating which tree best fits what's known at present makes the science real.

**The examples are what to expect from novices—not experts. They may be "technically wrong" in some respects, but they are "intelligently wrong" in most.**

Below are two examples of plausible trees of common ancestry based on the presence of obviously shared features. “Earthworms” are not Blorfs, but Blorfs and earthworms have bodies with front and rear ends. Quite likely, front-to-rear body style preceded limbs and head adornments. Heads before horns! All of these creatures qualify as Dirgots. The arrows branching from Floomps end at the horns-on-head and antlers-on-head groups. Both groups are Floomps.



This second tree shows another equally logical and equally valid (given the criteria and information at hand) solution to the puzzle. It gives priority to the feature of head adornments. If standing on two toes is judged to be more fundamental, then rhinos and horses belong in a closely related group (the odd-toe standers) as do cows, moose, and deer (the even-toe standers). That approach would yield a third, and equally valid, solution. This tree, however, only distinguishes "toe-standers."

Knowledge of "stomachs" has not been utilized in constructing either tree. It could have—stomach chambers vary from one group of mammals to another. For example, moose ruminate and have antlers; cows ruminate and have horns; horses do not ruminate and have no head ornaments. Features of skulls, limbs, digestion, limbs, and organs—and, of course, DNA sequences—combine to find the most likely tree structures.