Whale Evolution – Teacher Instructions

Model Deployment Activity – Becoming Whales

When copying the fossil strips for student use, be sure to remove fossil strip #6.

Pre-activity discussion
What evidence do we have that organisms have changed? How do we know what they looked like in an earlier time?

Begin whale evolution PowerPoint.
Slide 1 – Ask students: Have you ever seen a whale? How big are they?

Slide 2 - What type of creature is a whale? Video link at bottom of slide will take you to a YouTube video of a humpback whale nursing. If you cannot access YouTube at school use another method of acquiring nursing whale footage.

What type of creature is a whale? Whales are mammals. Ask: what are some other mammals? Do whales look like these other mammals? No, do all whales look similar? What are common traits whales share? Show slides 3 and 4.

From where did whales arise? Show slide 5 – Darwin's ideas

How can we determine whale origins? What are fossils?

Instructions
Activity 1 – Whales in Transition - Slides 6 and 7 have directions for this activity.

Let's look at some pictures of whale fossils. Distribute envelopes of whale fossils and student reading.

Have students make a time line from 35mya to 50 mya on a whiteboard. Slide 8 shows the Eocene time line - As they read the whale hunt (#1-5) they should place whale strips on the time line.

Slides 9 – 13 show pictures of each animal, its skeleton and teeth.

Slide 14 has directions for drawing a prediction. How would #6 look.

In a board meeting compare student predictions. Discuss similarities and differences in student predictions. Have students explain why they chose to include certain traits. Show slide 15 and have students compare the actual animal to their prediction. Slide 16 is an artist depiction of an Ambulocetus in its habitat.

Have students answer the discussion questions at the end of the student reading in their notebooks. Assign specific questions to groups to whiteboard. Hold a WB meeting to discuss the responses. Ask students to identify characteristics of early whale ancestors make sure they include hooves. Ask students what mammals alive today have hooves?

Slide 17 asks "what is the closest land dwelling relative of whales?" Slide 18 – A cladogram of early whale ancestors to modern day whales, discuss with students the "blind" alley of Mesonychids and how the cladagram supports the discussion held in the whiteboard meeting.

Slides 19 and 20 depict modern day hooved animals Slide 21 - Is there a way to demonstrate relatedness between whales and hooved mammals? Lead students to the idea that DNA can be used to demonstrate relatedness. Ask: What do you know about DNA? How is used to show who is the "daddy" or who committed the crime? Is DNA passed on? Is it exactly the same for all creatures that are related?

We will compare a small sequence of DNA for hooved mammals and whales.

Activity 2 – DNA Comparison Distribute the 11 DNA strips and the data sheets to student groups of four.

Students will align the DNA sequence for two species and count the number of places where the bases differ. Slide 22 – Example of how to compare

Next, record the number of differences the appropriate box on the data sheet. Continue the comparison and counting until all cells in the data table are complete.

Create class data on board, overhead transparency or document camera. Have groups add their data to this table. Make sure consensus is reached and all students have the same data. Slide 23 – Answer key for the data table

Have students answer the discussion questions in their small groups. These answers will assist them in creating the cladogram.

Draw the cladogram on the whiteboard. Hold a board meeting to share cladograms.

Discuss process used to construct cladagram, discuss what type of information can be gleaned from the cladogram. Who is the whales closest land dwelling hooved cousin? Slide 24 gives the answer.

Slide 25 - Farewhale Post-activity discussion
Ask students to list the elements of the process of science reflected in this lesson and give examples of each (for example):
a. recognition of a problem: how did whales emerge from some land-dwelling mammal?
b. hypothesis formation: they evolved by gradual change over time, losing terrestrial features, and gaining aquatic adaptations.
c. predictions based on hypothesis: what to look for (fossil whales with legs), where to look (Eocene sediments from warm shallow seas)
d. searching for evidence: (digging for whale fossils in Pakistan, etc.
e. popular "generally accepted" concepts replaced with new concepts, based on new evidence (DNA analysis).

Name______________________________________ Date_______

Model 3 – Evolution Activity 1

WHALES IN TRANSITION - Fossils

1. For many years, we have been finding a number of fossils of various **primitive whales** between 25 and 45 million years old (for which time frame **no** fossils of strictly modern type whales have been found). Examples of these early whales would include ***Dorudon, Prozeuglodon***, and ***Zygorhiza***. Place the **fossil picture strip #1** at about 36 mya on your timeline (actual range about 40-36 mya)

2. As more fossils have been discovered from the early Eocene epoch (55-33 mya), scientists searched for a land mammal from which whales would have most likely evolved. The group of animals that had the most features common to the earliest primitive whales found was called the **Mesonychids**. A typical example of these animals (e.g. *Pachyaena*, or *Sinonyx*) looked something like a wolf or hyena, with a large head, but with tiny **hooves** on all its toes! These are considered closely related to the even-toed hooved animals of today known as **artiodactyls**, with many branches evolving into modern deer, cattle, pigs, and hippos. **Place the mesonychid strip (#2)** at about the 55 mya level on your timeline (mesonychids lived from 60-35 mya). Whale specialists generally agreed that features such as **teeth** and various other skull features placed the now extinct mesonychids as the most likely group of land animals from which all whales of today evolved.

3. This picture of whale evolution was about all we had until **1983**, when the first of a series of discoveries began to fill the empty gap between land animals and whales. That first discovery (reported by whale specialist **Philip Gingerich** and others) was ***Pakicetus***. **Place the *Pakicetus* strip (#3)** on the timeline. It was a fragmented **skull**, with lots of teeth, found in Pakistan in sediments about 50 my old. Some of its teeth were very similar to those in mesonychids, while other teeth resembled those found in the later archaeocetes. Some of its other skull features (including its shape) were also similar to late Eocene whales like *Dorudon*. It was found in river sediments near what was once a shallow sea.

4. In **1990**, in Egypt, **Gingerich** and others reported the discovery of the fossilized **hind limbs** of a large, slender previously known primitive whale known as ***Basilosaurus***, around 37 my old (actually lived from 46 to 36 mya). Its hind limbs were proportionally very tiny (about 35 cm of foot and lower leg), and clearly unable to support any movement on land, but they were better developed than those found embedded in the hip region of some modern whales today. **Add *Basilosaurus* (#4)** to your timeline.

5. In early **1994**, **Gingerich** and others found the remains of ***Rodhocetus***, with well-developed hip bones, (and about 9 million years older than *Basilosaurus*). *Rodhocetus* is about 46 my old. From what we have of its skeleton, we conclude that its hind legs were at least somewhat functional. However, its vertebrae suggest powerful tail muscles, suggesting typical whale-like swimming, possibly with tail flukes. Its skull possessed certain whale-like features, including placement of nostrils further back on the head (toward the blowhole position), and enlarged ear capsule bones, typical of whales. **Place *Rodhocetus* (#5)** on the timeline.

6. At this point, notice the critical **gap** between 50 and 46 mya. Although there are some apparently related fossils from those gaps, there are none showing clearly what the limbs or bodies were like for that period. Since *Rodhocetus* clearly had somewhat functional hind limbs (as indicated by the fairly robust pelvic bones), they were considerably reduced as compared with mesonychids. Discuss with your teammates what traits you would expect to find (in the **head**, **limbs**, **tail**, and **body**) in a fossil from that period which would be an **intermediate stage** of an animal evolving from a mesonychid into an animal like *Rodhocetus*. **Describe** those traits, then **illustrate** your predictions by making a sketch on the whiteboard. Predict what region of the world, and in rocks of what age, would you expect to find this intermediate stage?

7. Show your teacher what your team predicted, and you will be handed the next discovery.

8. In late 1994, **Hans Thewissen** (formerly one of Gingerich's students), and his team, reported the discovery in 48 million year old deposits in Pakistan of a nearly complete fossil with teeth similar to mesonychids and early whales. He called it ***Ambulocetus***. Place the ***Ambulocetus*** **strip (#6)** on the timeline. It was about the size of a large sea lion. Its tail was long and slender, with no evidence of use for swimming. However, it had rather short, strong hind limbs, with huge feet (each toe with a tiny mesonychid-type hoof!). The head had a long snout with no blowhole. It probably walked on land like a sea lion, and swam with an undulating up and down motion of its hindquarters (like a sea otter), getting most of its propulsion force from its large feet. It was clearly a 4-legged cetacean.

DISCUSSION QUESTIONS

(Discuss these with your team, record your answers, and be prepared to share with the class)

1. Which typical whale traits were the **earliest** to appear?

2. Which whale traits evolved much **later**?

3. What **age** sediments, and in what **region** of the world, would you search now to get the fossils which would shed more light on whale origins, and what specific **traits** would you expect to find?

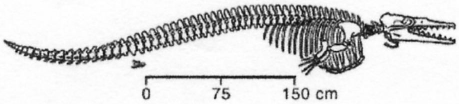
4. How closely did your "predicted traits" (expected for an **intermediate** between mesonychids and *Rodhocetus*) match the *Ambulocetus* fossil found? Does *Ambulocetus* seem to fit fairly well into the sequence between mesonychids and *Rodhocetus*?

5. As each new "intermediate fossil" was found, filling a "gap", how many new gaps were formed?

6. Several species of modern whales have well-developed rear limbs while embryos. As the embryo continues to mature, these limbs atrophy (shrink) and become nonfunctional. Why do you suppose this happens? (Why do the limbs form, and then why do they atrophy?)

7. What are some common traits of the earliest whale ancestors?

WHALES IN THE MAKING



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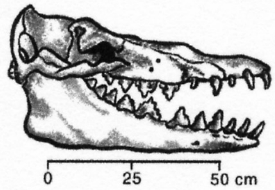

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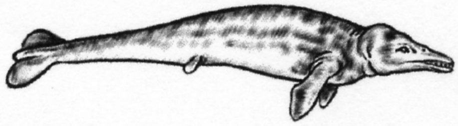

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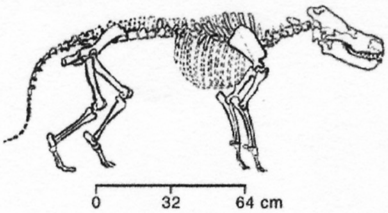
1. Archaeocetes (primitive whales, e.g.: *Dorudon, Prozeuglodon*)



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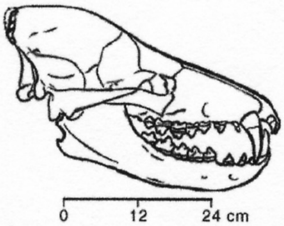

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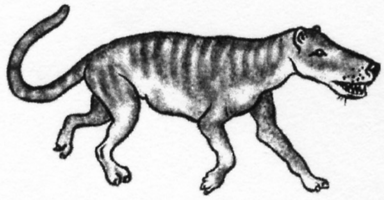

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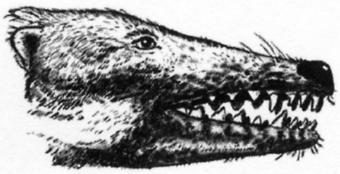
2. Mesonychids (extinct land mammals, with whale-like teeth, e.g. *Pachyaena, Sinonyx,*)



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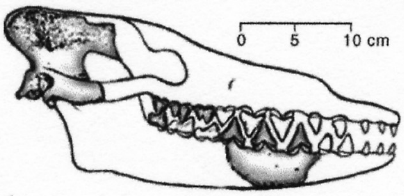

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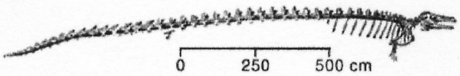
3. (1983) *Pakicetus inachus* (skull and teeth only)



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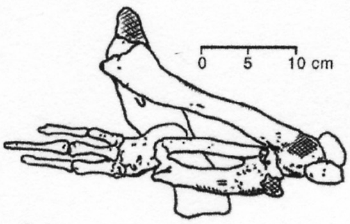

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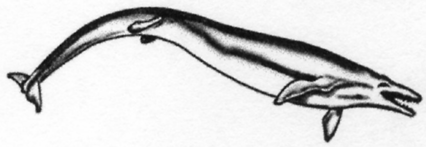

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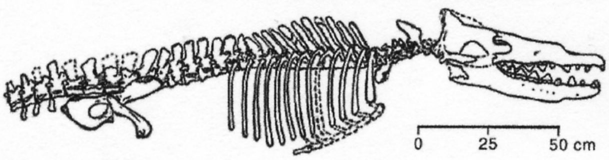
4. (1990) *Basilosaurus isis* (hind leg found)



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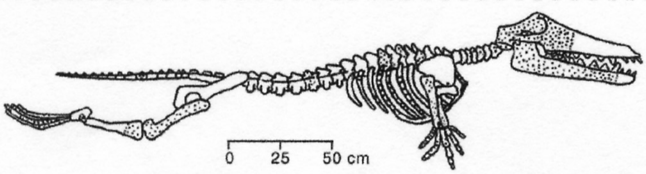
5. (1994) *Rodhocetus kasrani*



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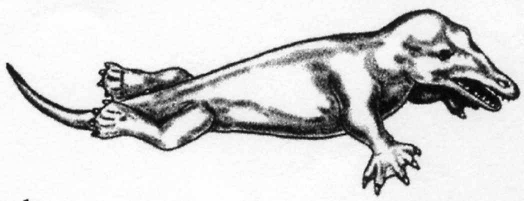

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6. (1994) *Ambulocetus natans*

All figures redrawn from originals for this lesson by Janet Dreyer. See "List of Credits" page for original sources.

Name____ Date_______

WHALES IN TRANSITION - DNA Activity

The plot thickens. We have narrowed the search for the origin of whales to a close connection with hooved mammals. The next question is: which one of the diverse members of that group are whales *most* closely aligned?

DNA to the rescue! As we learn the DNA sequences of more and more organisms, we can compare corresponding sequences to see which living species have DNA that is most alike. The more time that has passed (the more distant the ancestry) the more differences we will find.

You will be provided with eleven DNA segments from the gene for beta-casein, a milk protein found in all mammals. The segment is 60 base pairs (bp) long, from bp 141 to bp 200 in the gene. That same corresponding segment is presented for 11 species, including 3 Cetaceans: Right Whale, Sperm Whale, and a Porpoise; 7 Artiodactyls: a Giraffe, a Hippo, a Cow, a Camel, a Deer, Domestic Pig, and a Peccary; and one Perissodactyl: the Indian Rhino.

PROCEDURE:

Align the DNA segments from two species and count the number of places where the bases differ. For each pair of species compared, place the number of differences in the proper space on the grid below.

RESULTS:

	R.Whale	S.Whale	Porpoise	Giraffe	Hippo	Cow	Camel	Deer	Pig	Peccary
S.Whale										
Porpoise										
Giraffe										
Hippo										
Cow										
Camel										
Deer										
Pig										
Peccary										
Rhino										

Name____ Date_______

Model 3 – Evolution Activity 2

WHALES IN TRANSITION - DNA Discussion

You will find that the numbers sort into two groups: Pairs with 2-4 differences, then pairs with 7-18 differences.

1. List the pairs of species with only 2-4 differences in their DNA (show number of differences for each pair)

2 Porpoise – Sperm Whale	3	3
3	3	4
3	3	4

2. There are 4 species that are found in all possible combinations with each other. What are those species? (Give common names, as used on the strips):

3. What does this suggest about how close those 4 species are related (or how relatively recent they branched from a common ancestry?

4. Then there are 3 species that are found in their own 3 possible combinations. What are those 3 species?

5. What does this suggest about how close those 3 species are related (or how relatively recent they branched from a common ancestry?

6. Notice that there is a gap in the number of differences between pairs of DNA segments, showing none with 5-6 differences, and only one with 7 differences. What two species show 7 differences?

7. What does that suggest about when those two species branched from each other relative to the other two groups previously discussed?

8. The remaining pairings all range between 8 and 18 differences in this segment of DNA. What are the 2 remaining species that were not listed already?

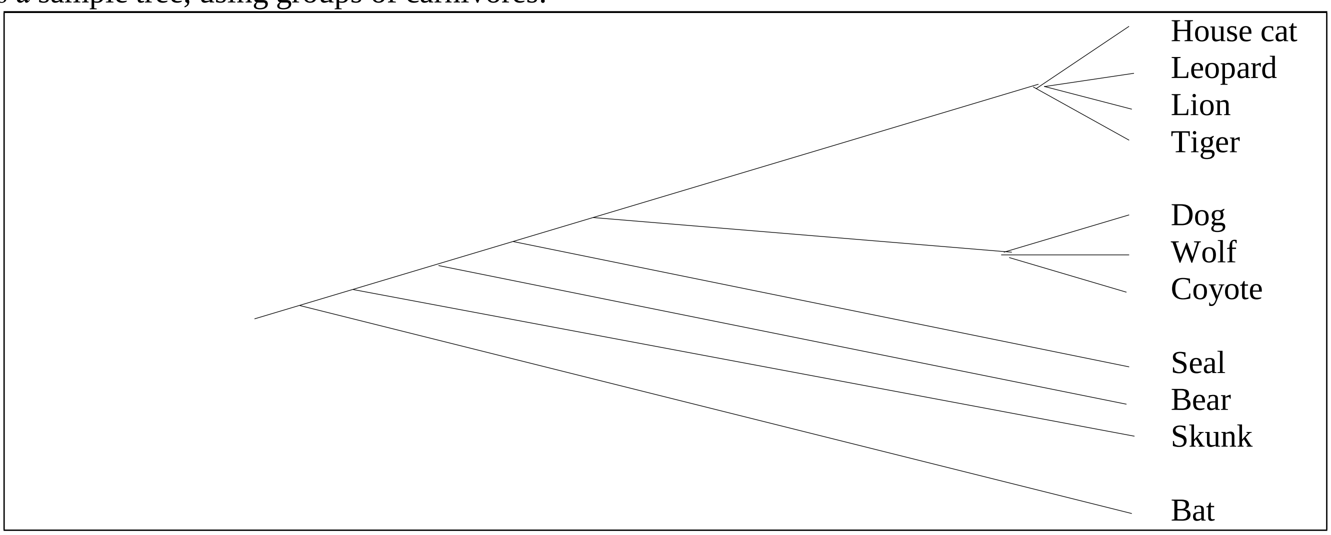
9. How do the 2 species in question 8 compare in common ancestry with,
   A) Species in question 2? More recent, about the same, or earlier?
   B) Species in question 4? More recent, about the same, or earlier?
   C) Species in question 6? More recent, about the same, or earlier?

10. As for our original question, to which species are cetaceans (whales) most closely related?

Comparing the specific numbers of differences between these last 4 species and those previous 7 species can be a little tricky, mainly because differences of 1-3 don't seem very significant, and the range is fairly wide (from 8 to 18, with no real gaps in the continuum). However, for our purposes, this isn't important.

11. Using the analysis you've made above, try drawing a "family tree" with all the species we've looked at here. Show short branches for closely related (recently branching) species, and longer branches for the more distantly related species. Label the common name for each species at the end of each branch Most people find it easier to draw the tree as if it's lying on its side, with the "trunk" end to the left, and the shorter branches on the right. You might want to practice before drawing it in neatly in lower box.

Here's a sample tree, using groups of carnivores:



Family Tree for Cetaceans and Artiodactyls:

DNA ANALYSIS

DNA segment from beta casein (milk protein): 60 bp segment (#141-200). Cut apart the 11 strips for aligning pairs and counting differences.

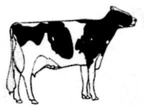
Rt. Whale AATCCCCAAAGCTAAGGAGACTATCCTTCCTAAGCATAAAGAAATGCCCTTCCCTATATC

Sp. Whale AGTCCCCAAAGCTAAGGAGACTCTCCTTCCTAAGCATAAAGAAATGCCCTTCCCTAAATC

Porpoise AGTCCCCAAAGCTAAGGAGACTATCCTTCCTAAGCATAAAGAAATGCGCTTCCCTAAATC

Giraffe AGTCTCCAAAGTGAAGGAGACTATGGCTCCTAAGCACAAAGAAATGCCCTTCCCTAAATA

Hippo AGTCCCCAAAGCAAAGGAGACTATCCTTCCTAAGCATAAAGAAATGCCCTTCTCTAAATC



Cow AGTCCCCAAAGTGAAGGAGACTATGGTTCCTAAGCACAAGGAAATGCCCTTCCCTAAATA

Camel TGTCCCCAAAACTAAGGAGACCATCATTCCTAAGCGCAAAGAAATGCCCTTGCTTCAGTC

Deer AGTCTCCGAAGTGAAGGAGACTATGGTTCCTAAGCACGAAGAAATGCCCTTCCCTAAATA

Pig AGATTCCAAAGCTAAGGAGACCATTGTTCCCAAGCGTAAAGGAATGCCCTTCCCTAAATC

Peccary AGACCCCAAACCTAAGGAGACCGTTGTTCACAAGCGTAAAGGAATGTCCTCCCCTAAATC

Rhino : AGTCCTCCAAACTAAGGAGACCATCTTTCCTAAGCTCAAAGTTATGCCCTCCCTTAAATC