

Supplemental Material

CBE—Life Sciences Education

Dees *et al.*

SUPPLEMENTAL MATERIAL

Table S1. Percentage of student responses that contained specific forms of reasoning to evaluate taxa relatedness for each instrument and style of phylogenetic tree.

Diagonal Phylogenetic Trees				
Taxa Relatedness Reasoning	Pre-HW [n=74]	Post-HW [n=75]	Unit Exam [n=81]	Final Review [n=72]
<i>Most Recent Common Ancestry</i>	14%	41%	51%	47%
<i>Monophyletic Grouping</i>	1%	0%	0%	0%
Counting Nodes	23%	28%	31%	32%
Counting Synapomorphies	35%	16%	10%	19%
Branch Tip Proximity	36%	13%	4%	1%
External Insights	5%	5%	2%	1%
Other Responses	8%	11%	14%	11%
Bracket Phylogenetic Trees				
Taxa Relatedness Reasoning	Pre-HW [n=74]	Post-HW [n=75]	Unit Exam [n=81]	Final Review [n=72]
<i>Most Recent Common Ancestry</i>	11%	53%	64%	57%
<i>Monophyletic Grouping</i>	4%	4%	1%	3%
Counting Nodes	28%	23%	23%	24%
Counting Synapomorphies	41%	13%	7%	19%
Branch Tip Proximity	22%	9%	5%	1%
External Insights	7%	3%	2%	1%
Other Responses	12%	5%	6%	7%
<i>Italics</i> indicate correct forms of reasoning for taxa relatedness. Student responses could include multiple forms of reasoning (percentages sum to greater than 100%). See Dees <i>et al.</i> (2014) for complete descriptions and student-generated examples of reasoning categories.				

Table S2. Percentage of phylogenetic trees constructed by students that contained specific errors for each instrument and style of phylogenetic tree.

Diagonal Phylogenetic Trees				
Major Errors	Pre-HW [n=74]	Post-HW [n=75]	Unit Exam [n=64][#]	Final Review [n=56][#]
Incorrect Relatedness	22%	13%	11%	11%
Incorrect Traits	27%	16%	19%	18%
Contemporary Descent	3%	4%	2%	0%
Minor Errors	Pre-HW [n=74]	Post-HW [n=75]	Unit Exam [n=64][#]	Final Review [n=56][#]
Empty Branches	42%	40%	39%	39%
Extra Nodes	61%	52%	52%	52%
Bracket Phylogenetic Trees				
Major Errors	Pre-HW [n=74]	Post-HW [n=75]	Unit Exam [n=17][#]	Final Review [n=16][#]
Incorrect Relatedness	22%	13%	0%	6%
Incorrect Traits	24%	15%	12%	13%
Contemporary Descent	3%	3%	6%	6%
Minor Errors	Pre-HW [n=74]	Post-HW [n=75]	Unit Exam [n=17][#]	Final Review [n=16][#]
Empty Branches	9%	4%	12%	13%
Extra Nodes	19%	8%	12%	6%
Side Branches*	16%	11%	18%	13%
[#] Students constructed one phylogenetic tree in the style of their choice during the unit exam and review activity for the final exam. *Error is unique to the bracket style. Student responses could include any combination of errors or no errors (percentages do not sum to 100%). See Dees and Momsen (2016) for complete descriptions and student-generated examples of errors.				

References

Dees J, Momsen JL (2016). Student construction of phylogenetic trees in an introductory biology course. *Evol Educ Outreach* 9, ar3.

Dees J, Momsen JL, Niemi J, Montplaisir L (2014). Student interpretations of phylogenetic trees in an introductory biology course. *CBE Life Sci Educ* 13, 666–676.

Instrument #1: Pre-Instructional Homework

The following interpretation and construction tasks referred to diagonal phylogenetic trees.

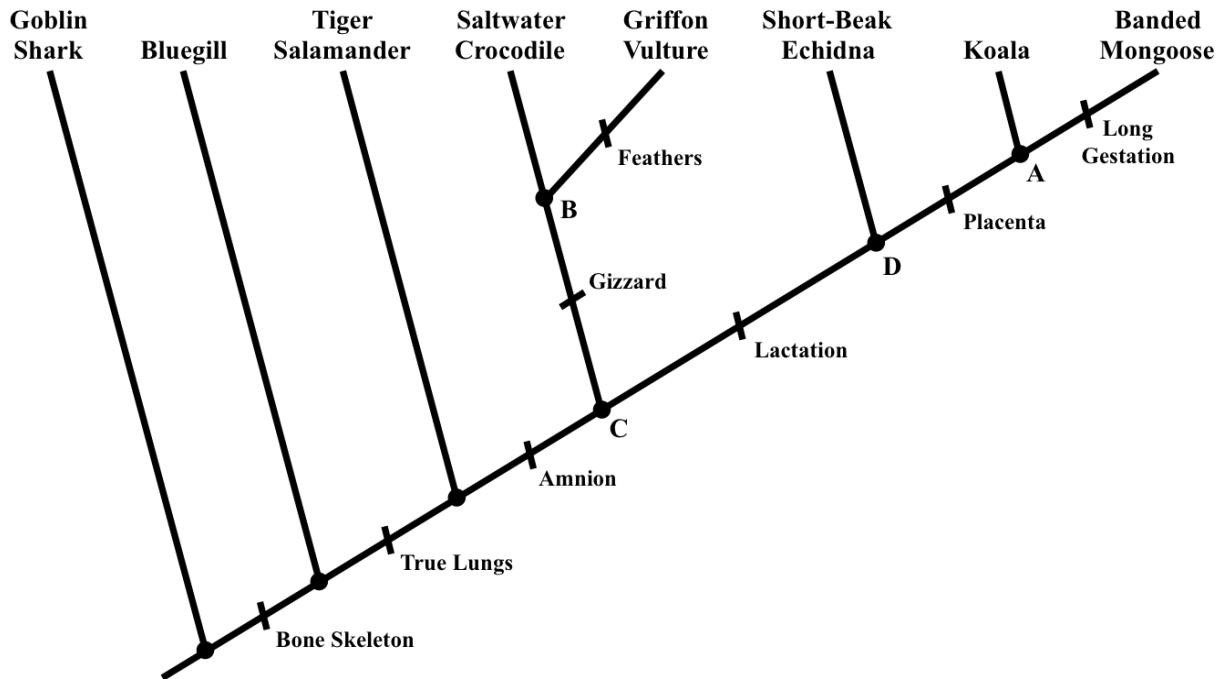


Figure 1: phylogenetic tree of vertebrates (diagonal style)

Most Recent Common Ancestor

Which node on the phylogenetic tree of vertebrates in Figure 1 represents the most recent common ancestor of griffon vultures and short-beak echidnas? Select one option.

node A node B node C node D

Monophyletic Group

On the phylogenetic tree of vertebrates in Figure 1, draw a circle around one monophyletic group that includes at least two species.

Contemporary Descent

According to the phylogenetic tree of vertebrates in Figure 1, did griffon vultures evolve from saltwater crocodiles? Select one option.

Yes No

Explain the reasoning for your choice.

Instrument #1: Pre-Instructional Homework (Continued)

Taxa Relatedness

According to the phylogenetic tree of vertebrates in Figure 1, how would you describe the relatedness of saltwater crocodiles to tiger salamanders and koalas? Select one option.

- Saltwater crocodiles are more closely related to tiger salamanders than koalas.
- Saltwater crocodiles are equally related to tiger salamanders and koalas.
- Saltwater crocodiles are more closely related to koalas than tiger salamanders.

Explain the reasoning for your choice.

Construction Task

Directions: Use the morphological traits in Table 1 to construct a phylogenetic tree of land plants in the diagonal style (see Figure 1 on the first page for an example of diagonal style). Be sure to label all synapomorphies on the phylogenetic tree.

Table 1: morphological traits of land plants (X = trait possessed)

		LAND PLANTS					
		Alligator Juniper	Alpine Clubmoss	Scarlet Banana	Bearded Pawwort	Queen Sago	Saguaro Cactus
TRAITS	Stomata	X	X	X		X	X
	Fruit			X			X
	Scale Leaves	X					
	Seeds	X		X		X	X
	Spines						X
	Cones	X				X	

Remember to construct a phylogenetic tree in the diagonal style (see Figure 1 for an example).

Instrument #1: Pre-Instructional Homework (Continued)

The following interpretation and construction tasks referred to bracket phylogenetic trees.

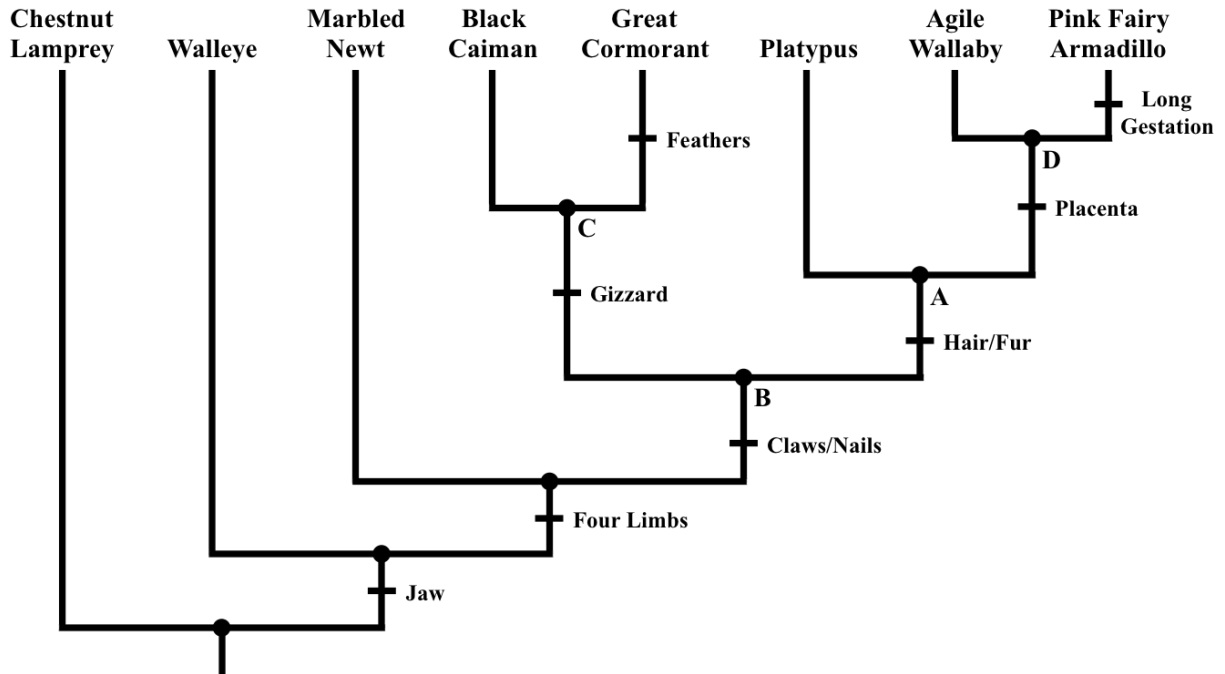


Figure 1: phylogenetic tree of vertebrates (bracket style)

Most Recent Common Ancestor

Which node on the phylogenetic tree of vertebrates in Figure 1 represents the most recent common ancestor of great cormorants and platypuses? Select one option.

node A node B node C node D

Monophyletic Group

On the phylogenetic tree of vertebrates in Figure 1, draw a circle around one monophyletic group that includes at least two species.

Contemporary Descent

According to the phylogenetic tree of vertebrates in Figure 1, did great cormorants evolve from black caimans? Select one option.

Yes No

Explain the reasoning for your choice.

Instrument #1: Pre-Instructional Homework (Continued)

Taxa Relatedness

According to the phylogenetic tree of vertebrates in Figure 1, how would you describe the relatedness of black caimans to marbled newts and agile wallabies? Select one option.

Black caimans are more closely related to agile wallabies than marbled newts.

Black caimans are equally related to marbled newts and agile wallabies.

Black caimans are more closely related to marbled newts than agile wallabies.

Explain the reasoning for your choice.

Construction Task

Directions: Use the morphological traits in Table 1 to construct a phylogenetic tree of land plants in the bracket style (see Figure 1 on the first page for an example of bracket style). Be sure to label all synapomorphies on the phylogenetic tree.

Table 1: morphological traits of land plants (X = trait possessed)

		LAND PLANTS					
		Swamp Rose	Bamboo Cycad	Bristly Haircap	Dragon Spruce	Durum Wheat	Sensitive Fern
TRAITS	Prickles	X					
	Pollen	X	X		X	X	
	Tracheids	X	X		X	X	X
	Naked Seeds		X		X		
	Needles				X		
	Flowers	X				X	

Remember to construct a phylogenetic tree in the bracket style (see Figure 1 for an example).

Instrument #2: Post-Instructional Homework

The following interpretation and construction tasks referred to diagonal phylogenetic trees.

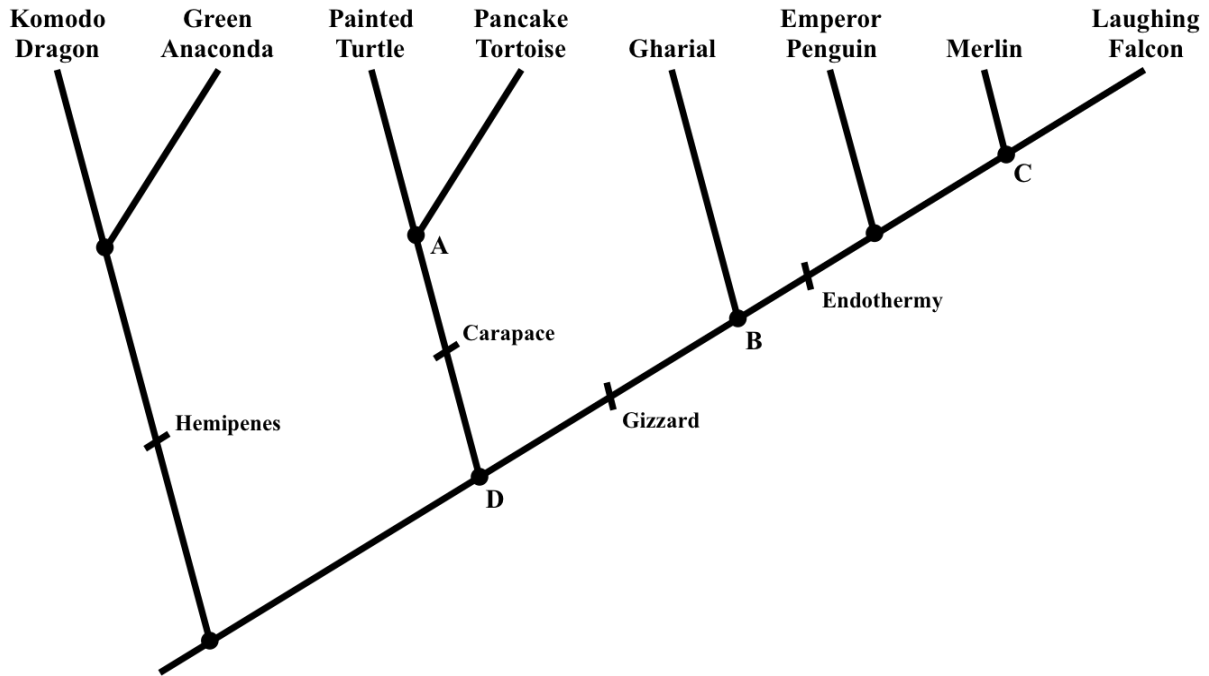


Figure 1: phylogenetic tree of reptiles and birds (diagonal style)

Most Recent Common Ancestor

Which node on the phylogenetic tree of reptiles and birds in Figure 1 represents the most recent common ancestor of pancake tortoises and gharials? Select one option.

node A node B node C node D

Monophyletic Group

On the phylogenetic tree of reptiles and birds in Figure 1, draw a circle around one monophyletic group that includes at least two species.

Contemporary Descent

According to the phylogenetic tree of reptiles and birds in Figure 1, did pancake tortoises evolve from painted turtles? Select one option.

Yes No

Explain the reasoning for your choice.

Instrument #2: Post-Instructional Homework (Continued)

Taxa Relatedness

According to the phylogenetic tree of reptiles and birds in Figure 1, how would you describe the relatedness of painted turtles to green anacondas and merlins? Select one option.

- Painted turtles are more closely related to merlins than green anacondas.
- Painted turtles are equally related to green anacondas and merlins.
- Painted turtles are more closely related to green anacondas than merlins.

Explain the reasoning for your choice.

Construction Task

Directions: Use the morphological traits in Table 1 to construct a phylogenetic tree of green plants in the diagonal style (see Figure 1 on the first page for an example of diagonal style). Be sure to label all synapomorphies on the phylogenetic tree.

Table 1: morphological traits of green plants (X = trait possessed)

		GREEN PLANTS					
		Venus Flytrap	Fragile Stonewort	Giant Sequoia	Golden Eardrops	Sugar Pine	Bridal Rainbow
TRAITS	Flowers	X			X		X
	Cones			X		X	
	Alternating Generations	X		X	X	X	X
	Snap Traps	X					
	Awl Leaves			X			
	Carnivory	X					X

Remember to construct a phylogenetic tree in the diagonal style (see Figure 1 for an example).

Instrument #2: Post-Instructional Homework (Continued)

The following interpretation and construction tasks referred to bracket phylogenetic trees.

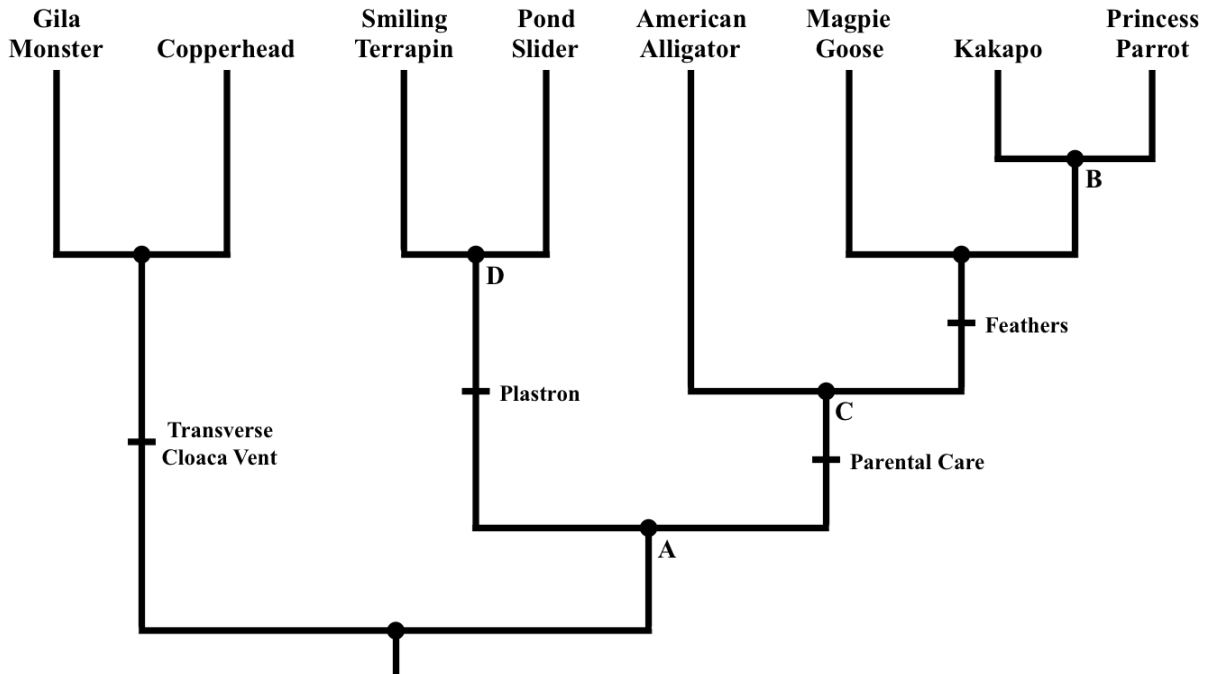


Figure 1: phylogenetic tree of reptiles and birds (bracket style)

Most Recent Common Ancestor

Which node on the phylogenetic tree of reptiles and birds in Figure 1 represents the most recent common ancestor of pond sliders and American alligators? Select one option.

node A node B node C node D

Monophyletic Group

On the phylogenetic tree of reptiles and birds in Figure 1, draw a circle around one monophyletic group that includes at least two species.

Contemporary Descent

According to the phylogenetic tree of reptiles and birds in Figure 1, did pond sliders evolve from smiling terrapins? Select one option.

Yes No

Explain the reasoning for your choice.

Instrument #2: Post-Instructional Homework (Continued)

Taxa Relatedness

According to the phylogenetic tree of reptiles and birds in Figure 1, how would you describe the relatedness of smiling terrapins to copperheads and kakapos? Select one option.

- Smiling terrapins are more closely related to copperheads than kakapos.
- Smiling terrapins are equally related to copperheads and kakapos.
- Smiling terrapins are more closely related to kakapos than copperheads.

Explain the reasoning for your choice.

Construction Task

Directions: Use the morphological traits in Table 1 to construct a phylogenetic tree of green plants in the bracket style (see Figure 1 on the first page for an example of bracket style). Be sure to label all synapomorphies on the phylogenetic tree.

Table 1: morphological traits of green plants (X = trait possessed)

		GREEN PLANTS					
		Cobra Lily	Old Man Orchid	Sikkim Larch	Felty Fingers	Sticky Starwort	Chestnut Dioon
TRAITS	Fronds						X
	Pitfall Traps	X					
	Naked Seeds			X			X
	Cuticle	X	X	X		X	X
	Fruit	X	X			X	
	Tricolpate Pollen	X				X	

Remember to construct a phylogenetic tree in the bracket style (see Figure 1 for an example).

Instrument #3: Unit Exam

The following interpretation tasks referred to a diagonal phylogenetic tree.

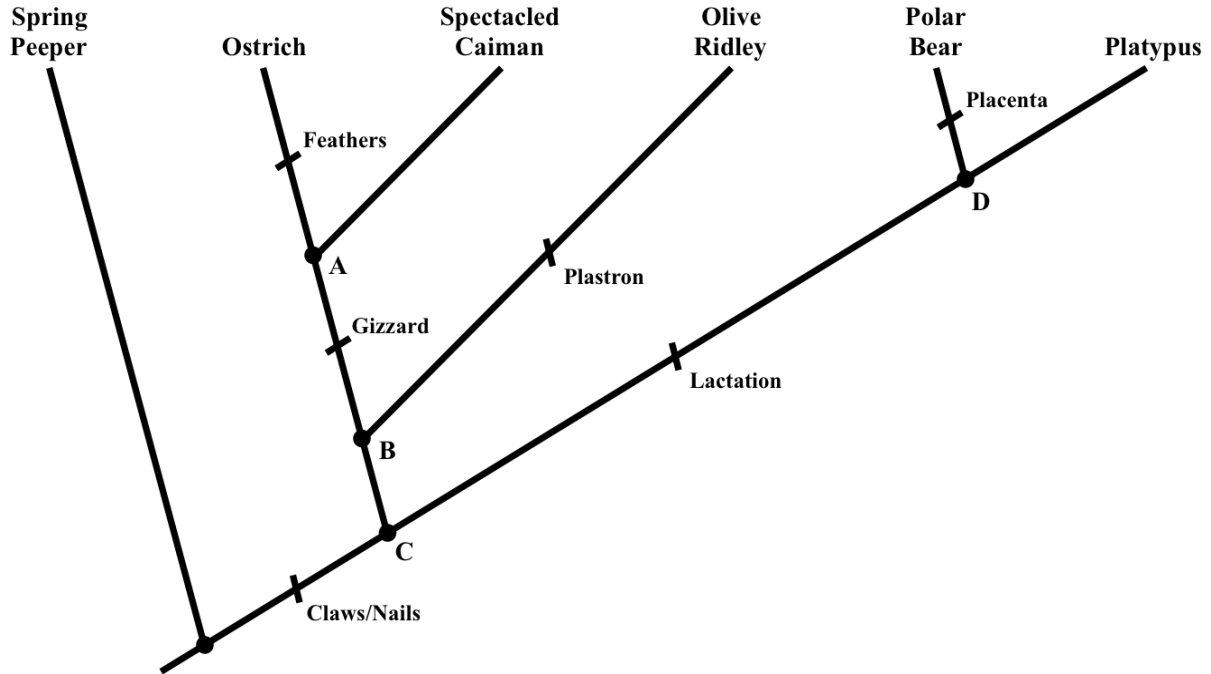


Figure 1: phylogenetic tree of tetrapods (diagonal style)

Most Recent Common Ancestor

Which node on the phylogenetic tree of tetrapods in Figure 1 represents the most recent common ancestor of spectacled caimans and polar bears? Select one option.

node A node B node C node D

Monophyletic Group

On the phylogenetic tree of tetrapods in Figure 1, draw a circle around one monophyletic group that includes at least two species.

Contemporary Descent

According to the phylogenetic tree of tetrapods in Figure 1, did olive ridleys evolve from ostriches? Select one option.

Yes No

Explain the reasoning for your choice.

Instrument #3: Unit Exam (Continued)

Taxa Relatedness

According to the phylogenetic tree of tetrapods in Figure 1, how would you describe the relatedness of polar bears to ostriches and olive ridleys? Select one option.

- Polar bears are more closely related to ostriches than olive ridleys.
- Polar bears are equally related to ostriches and olive ridleys.
- Polar bears are more closely related to olive ridleys than ostriches.

Explain the reasoning for your choice.

The following interpretation tasks referred to a bracket phylogenetic tree.

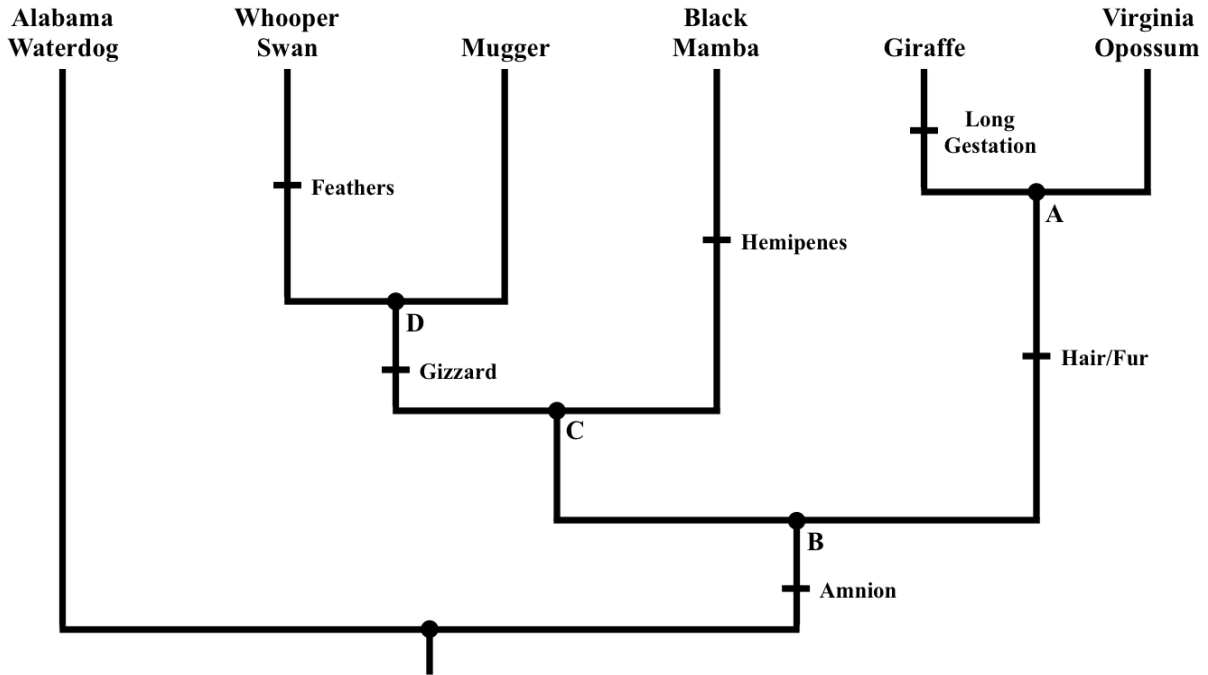


Figure 2: phylogenetic tree of tetrapods (bracket style)

Most Recent Common Ancestor

Which node on the phylogenetic tree of tetrapods in Figure 2 represents the most recent common ancestor of muggers and giraffes? Select one option.

- node A
- node B
- node C
- node D

Instrument #3: Unit Exam (Continued)

Monophyletic Group

On the phylogenetic tree of tetrapods in Figure 2, draw a circle around one monophyletic group that includes at least two species.

Contemporary Descent

According to the phylogenetic tree of tetrapods in Figure 2, did black mambas evolve from whooper swans? Select one option.

Yes No

Explain the reasoning for your choice.

Taxa Relatedness

According to the phylogenetic tree of tetrapods in Figure 2, how would you describe the relatedness of giraffes to whooper swans and black mambas? Select one option.

Giraffes are more closely related to black mambas than whooper swans.

Giraffes are equally related to whooper swans and black mambas.

Giraffes are more closely related to whooper swans than black mambas.

Explain the reasoning for your choice.

The following single construction task allowed students to use the style of their choice.

Use the morphological traits in Table 1 to build a phylogenetic tree of vascular plants in the style of your choice (see Figures 1–2 for examples). Be sure to label all synapomorphies.

Table 1: morphological traits of vascular plants (X = trait possessed)

		VASCULAR PLANTS					
		Bobtail Barley	Maidenhair Spleenwort	Virginia Creeper	Bishop Pine	Skeleton Fork Fern	Western Redcedar
TRAITS	Cones				X		X
	Flowers	X		X			
	Tricolpate Pollen			X			
	Seeds	X		X	X		X
	Fronds		X				
	Scale Leaves						X

Instrument #4: Review Activity for the Final Exam

The following interpretation tasks referred to a diagonal phylogenetic tree.

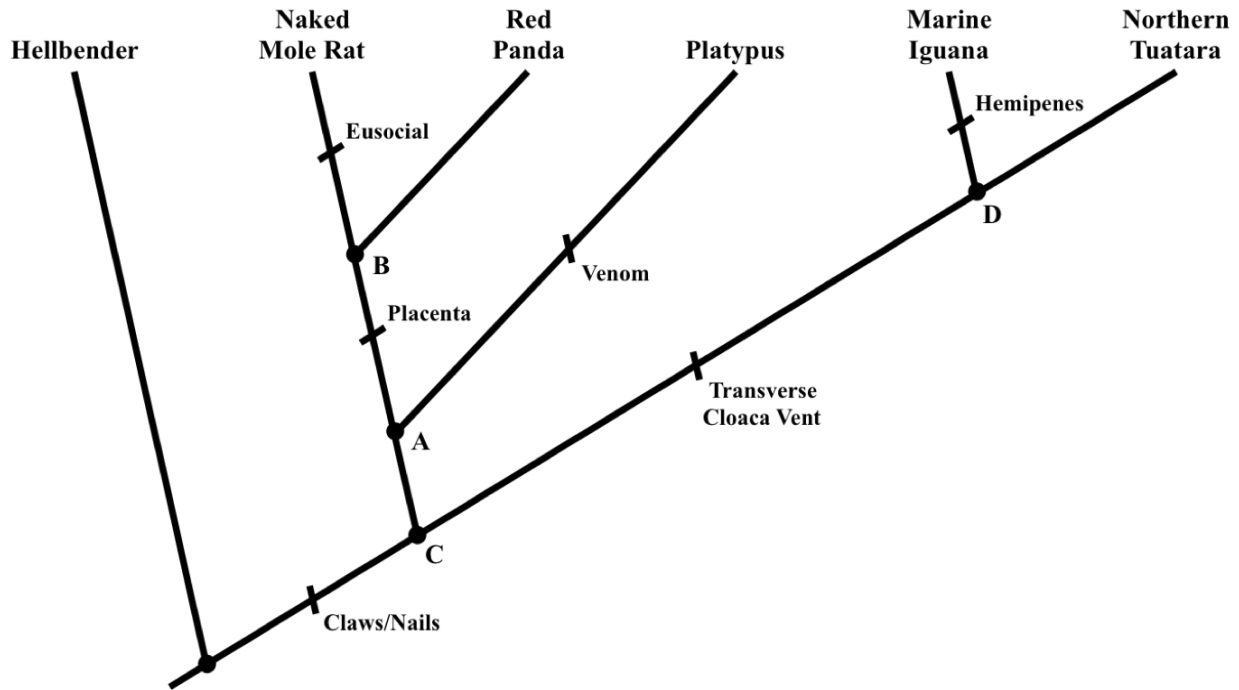


Figure 1: phylogenetic tree of tetrapods (diagonal style)

Most Recent Common Ancestor

Which node on the phylogenetic tree of tetrapods in Figure 1 represents the most recent common ancestor of red pandas and marine iguanas? Select one option.

node A node B node C node D

Monophyletic Group

On the phylogenetic tree of tetrapods in Figure 1, draw a circle around one monophyletic group that includes at least two species.

Contemporary Descent

According to the phylogenetic tree of tetrapods in Figure 1, did platypuses evolve from naked mole rats? Select one option.

Yes No

Explain the reasoning for your choice.

Instrument #4: Review Activity for the Final Exam (Continued)

Taxa Relatedness

According to the phylogenetic tree of tetrapods in Figure 1, how would you describe the relatedness of marine iguanas to naked mole rats and platypuses? Select one option.

- Marine iguanas are more closely related to naked mole rats than platypuses.
- Marine iguanas are equally related to naked mole rats and platypuses.
- Marine iguanas are more closely related to platypuses than naked mole rats.

Explain the reasoning for your choice.

The following interpretation tasks referred to a bracket phylogenetic tree.

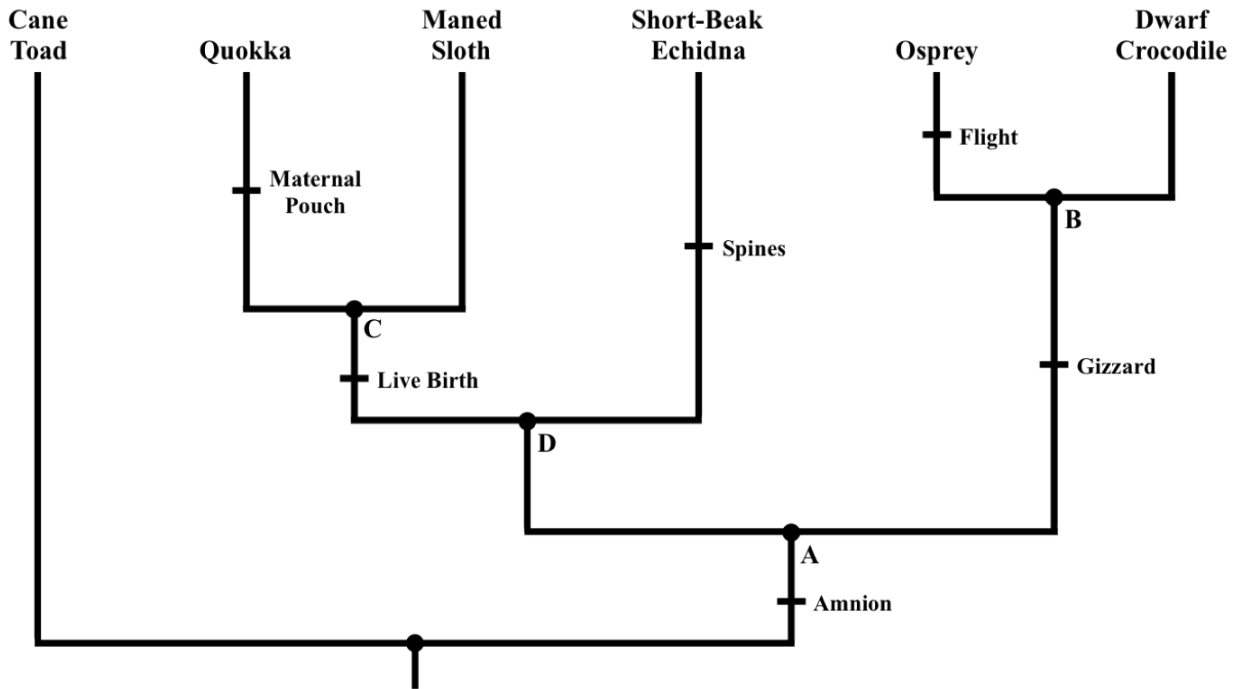


Figure 2: phylogenetic tree of tetrapods (bracket style)

Most Recent Common Ancestor

Which node on the phylogenetic tree of tetrapods in Figure 2 represents the most recent common ancestor of maned sloths and ospreys? Select one option.

- node A
- node B
- node C
- node D

Instrument #4: Review Activity for the Final Exam (Continued)

Monophyletic Group

On the phylogenetic tree of tetrapods in Figure 2, draw a circle around one monophyletic group that includes at least two species.

Contemporary Descent

According to the phylogenetic tree of tetrapods in Figure 2, did short-beak echidnas evolve from quokkas? Select one option.

Yes No

Explain the reasoning for your choice.

Taxa Relatedness

According to the phylogenetic tree of tetrapods in Figure 2, how would you describe the relatedness of ospreys to quokkas and short-beak echidnas? Select one option.

Ospreys are more closely related to short-beak echidnas than quokkas.

Ospreys are equally related to quokkas and short-beak echidnas.

Ospreys are more closely related to quokkas than short-beak echidnas.

Explain the reasoning for your choice.

The following single construction task allowed students to use the style of their choice.

Use the morphological traits in Table 1 to build a phylogenetic tree of vascular plants in the style of your choice (see Figures 1–2 for examples). Be sure to label all synapomorphies.

Table 1: morphological traits of vascular plants (X = trait possessed)

		VASCULAR PLANTS					
		Giant Dioon	Swollen Bladderwort	Meadow Horsetail	Sweet Potato	Limber Pine	Hairy Lip Fern
TRAITS	Needles					X	
	Pollen	X	X		X	X	
	Suction Traps		X				
	Sori						X
	Fruit		X		X		
	Naked Seeds	X				X	