Idea

- Solicit authors for an edited book focused on practicing scientific thinking
- Each chapter is a short "case study" focused on describing context, proposing hypotheses, collecting data, testing hypotheses, and using a scientific approach for the ultimate purpose of engaging in evidence-based revision of curricula and teaching strategies
  - Grounded in a discipline but approaches transcend disciplines
  - Adopt a similar approach: Why? How? What?
- I am committed to editing and have access to some funding for publication fees

"The first principle is that you must not fool yourself and you are the easiest person to fool."

Richard Feynman

As educators trying to be better educators, we suffer from confirmation bias?

Translation: we are not doing as well as we think we are

Practicing scientific teaching

- Scientific teaching involves enacting practices that enabling data-driven revision of curricula and teaching strategies.
- As with the pursuit of science for making sense of the world, scientific teaching begins with potentially falsifiable claims.
  - Example claim: My instruction improved student understanding
  - Example claim: My instruction improved students' abilities to be critical thinkers
- Can you confidently refute the null? How large and what direction is the effect of your teaching?
- The approach is as important as the outcomes
- The approach is useful for the pursuit of the scholarship of teaching and learning and for developing an "excellent" teaching dossier
  - Publication in SOTL journals
  - Development of a teaching dossier for P&T

SOTL example

Accepted by the Journal of College Science Teaching

Building bridges: An active learning lesson in evolution and collaboration

Carscadden, K.A.*, McDermott, M., Turbek, S., Tittes, S. & Martin, A. (Univ. of Colorado Boulder)
*kelly.carscadden@colorado.edu

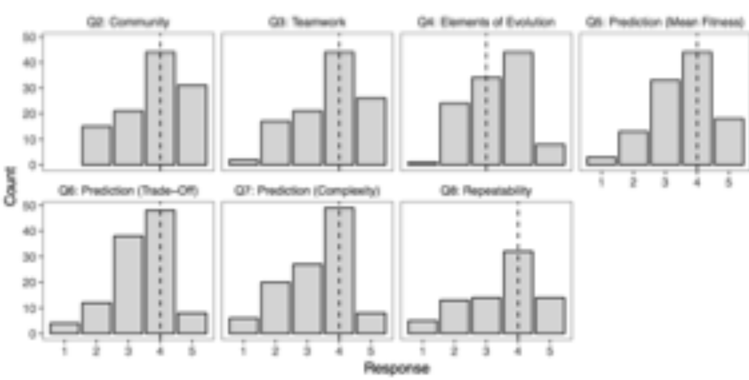
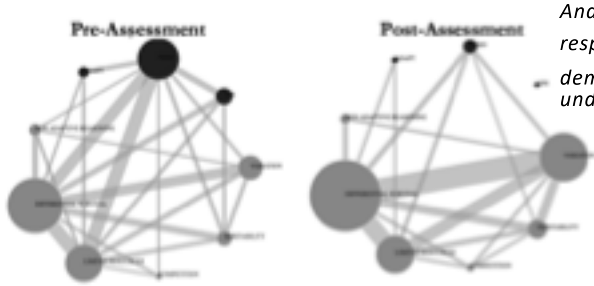


Figure 4. Student Assessment of Learning Gains quiz responses. Panels refer to survey questions from Table 2. Responses are: No gain (1), A little gain (2), Moderate gain (3), Good gain (4), Great gain (5), or NA (not shown). Dashed lines are median response scores, across all lab sections (n = 117 of 136 enrolled students completed the survey).

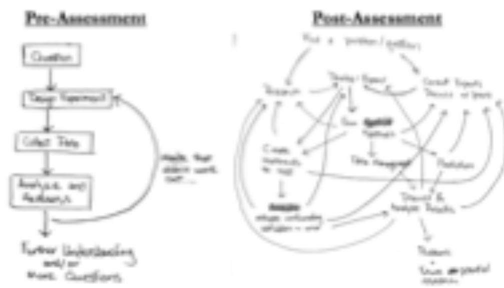
Example data from SALG

This meets the criterion from Article 5, section D, 2.B. Standards for Tenure from Regent policy *"A recommendation of tenure based on excellence in teaching or scholarly/creative work shall include evidence of impact beyond the institution."*

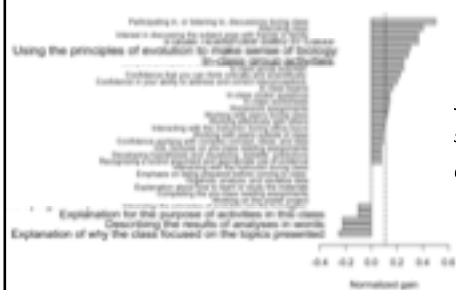
Dossier examples: Nancy Emery, EBIO



Analysis of free responses for demonstrating understanding

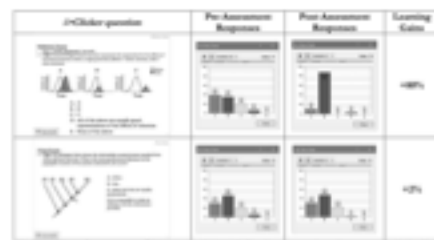


Concept mapping



Student survey data

Concept inventory type assessment



Emphasis in the dossier is on WHY the data were collected and HOW the data were used to revise and improve teaching and learning

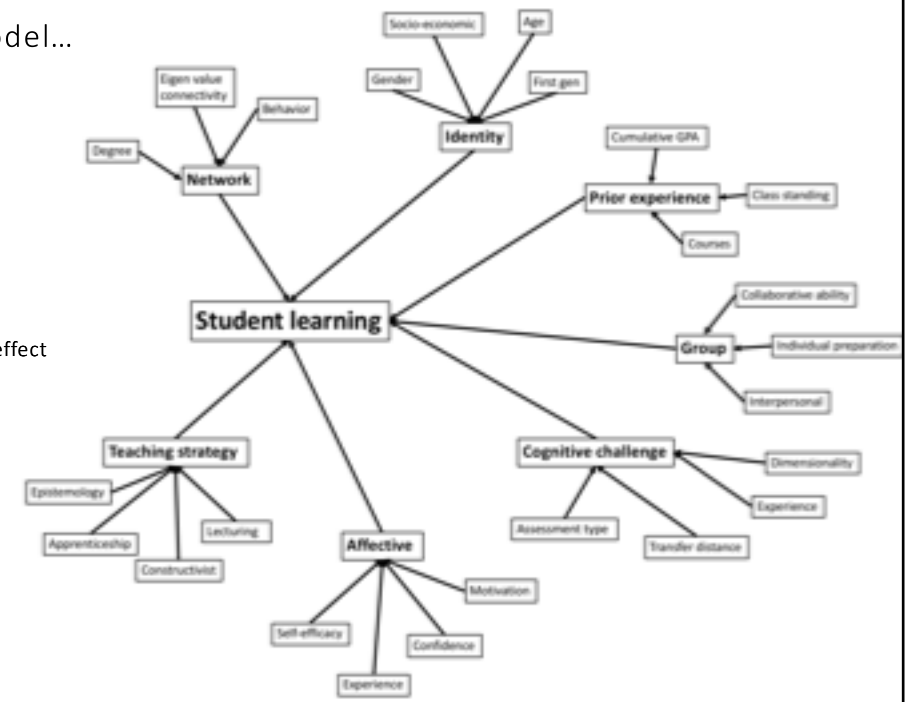
Practicing scientific teaching

What does this mean?

Begin with a working model…

Simplified model

Arrows indicate direction of effect



… or other educational frameworks ("theories of learning")…

Theories of learning

- **Behavioralism**
  - Behavioralism emphasizes a reductionistic notion of learning: a stimulus triggers a response and the response become more and more correct with practice.
- **Cognitivism**
  - Cognitivism emphasizes knowledge acquisition, the construction of mental models, and the processing of information.
- **Constructivism**
  - Constructivism is a broadly encompassing idea of how intellect develops through the assimilation of new information and the accommodation of an individual's particular world view to account for new information
- **Others**
  - **Socio-culturalism**
  - **Enactivism**
  - **Intuitionism**

Theories of motivation

- **Value-expectancy**
  - Student and teacher motivation reflects perceptions of value and probability of success
- **Attribution**
- **Self determination**
  - Confidence, self-regulation and and intrinsic motivation underlying learning (and teaching) success

…or perhaps with a theory of change

Fundamental theorem of evolution (the Price equation)

Change in a trait (e.g. cognitive ability)

Effect of other factors (e.g. group effects)

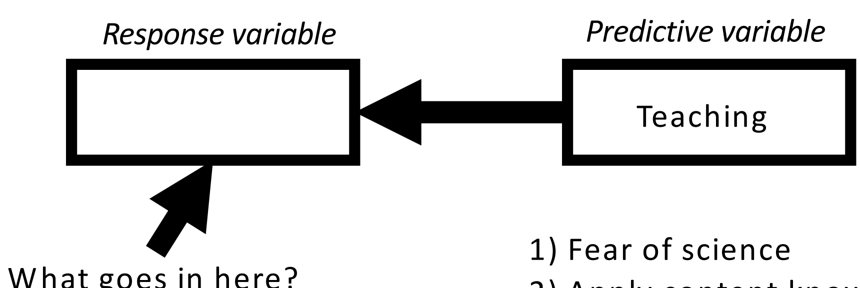
$$\Delta z = \frac{1}{w}\operatorname{cov}(w_i, z_i) + \frac{1}{w}\operatorname{E}(w_i\,\Delta z_i).$$

Average fitness

The covariance of fitness on the trait value of an individual in a population (i.e. the effect of selection)

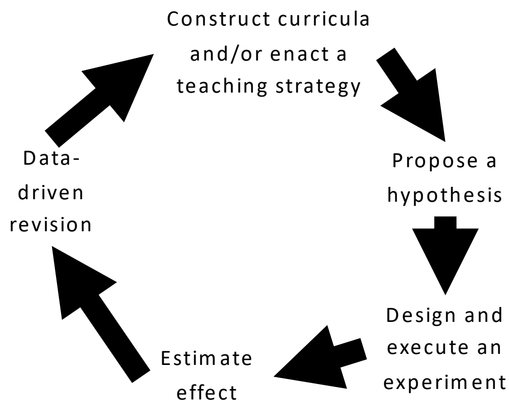
For teaching and learning, this is the covariance of performance on the trait value of an individual in a population (i.e. the effect of instruction)

…after you know WHY you want to pursue gathering data, you have to know HOW to get the data and knowing HOW depends on WHAT you want to know



1) Fear of science
2) Apply content knowledge
3) Conceptual understanding
4) Confidence

Practicing scientific teaching



Hypotheses:
My instruction, curricula, whatever…
1) …has no effect
2) …has a positive effect
3) …has a negative effect

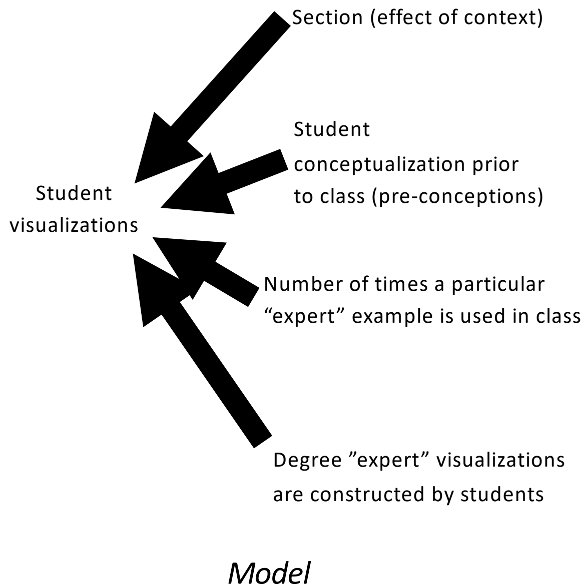
Once you have "objective" data on the effect, you can use the data for revision

Two examples of practicing scientific thinking

- Students use of visualization for explaining evolution (and their understanding of evolution) with Katie Ryan, undergraduate student
- Interpreting phylogenetic trees

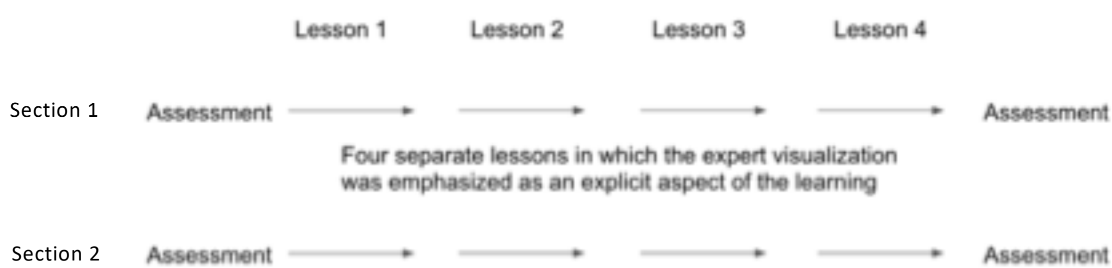
I am currently working on these from my last iteration to revise the curricula and teaching strategies

Students use of visualization for explaining evolution



- Same study executed in two different sections of same course
- Students complete a pre-assessment
- Expert visualization of evolution used multiple times during the semester
- How students engage with the information

Experimental design



Importantly: We **NEVER** told students…"This is what you should draw if your are ever asked to visualize evolution."
We wanted to know what they CHOOSE to draw after a course that emphasizes a particular visualization of evolution.

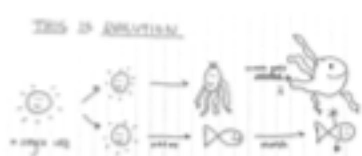
Assessment question

"What does evolution look like?"

"Explain evolution. In your answer, consider developing some sort of visualization (an illustration, graph, diagram, *etc*) that is useful for effectively explaining evolution."

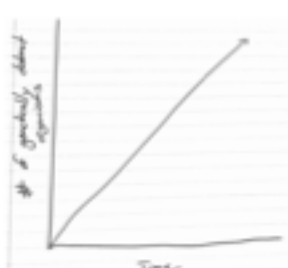
Coding student answers

0 = no visualization

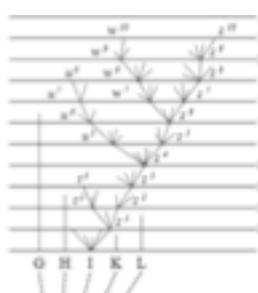


1 = linear sequence of evolutionary "stages"

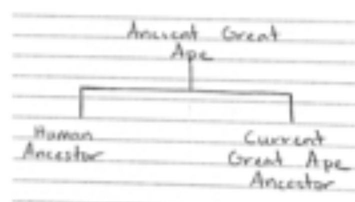
2 = specific scenario (example is black and white moths on bark)



3 = graph



4 = Darwinian (expert answer)

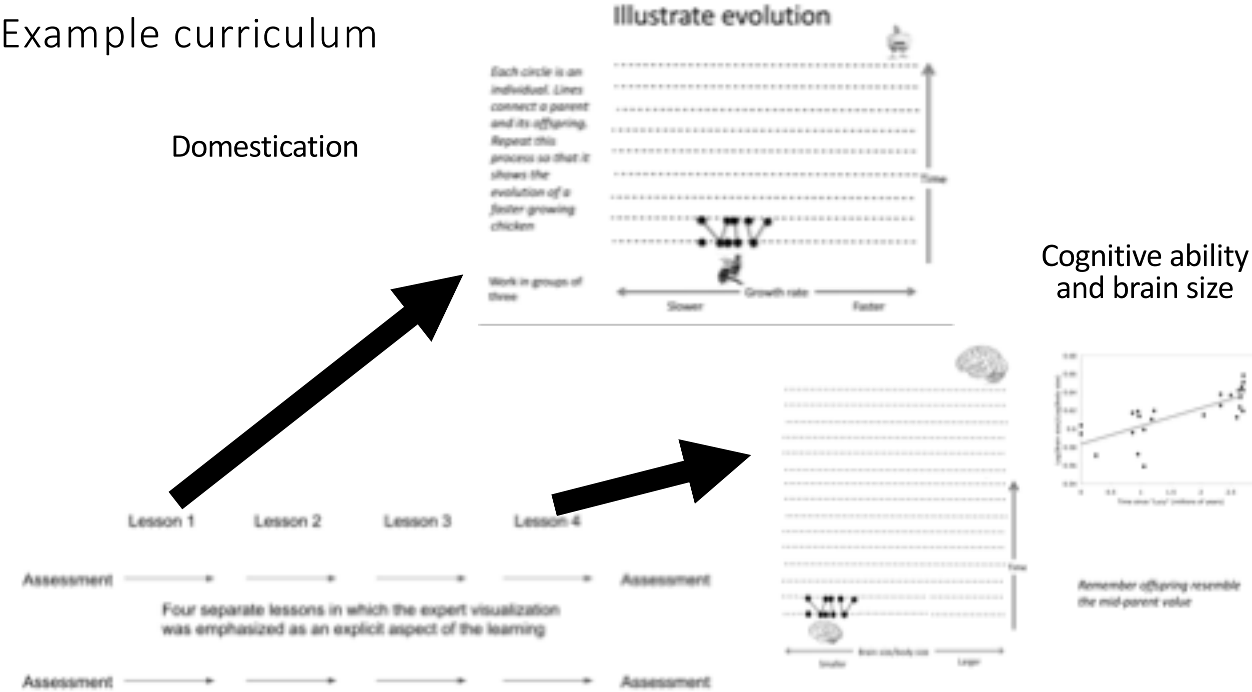


5 = tree

Example curriculum

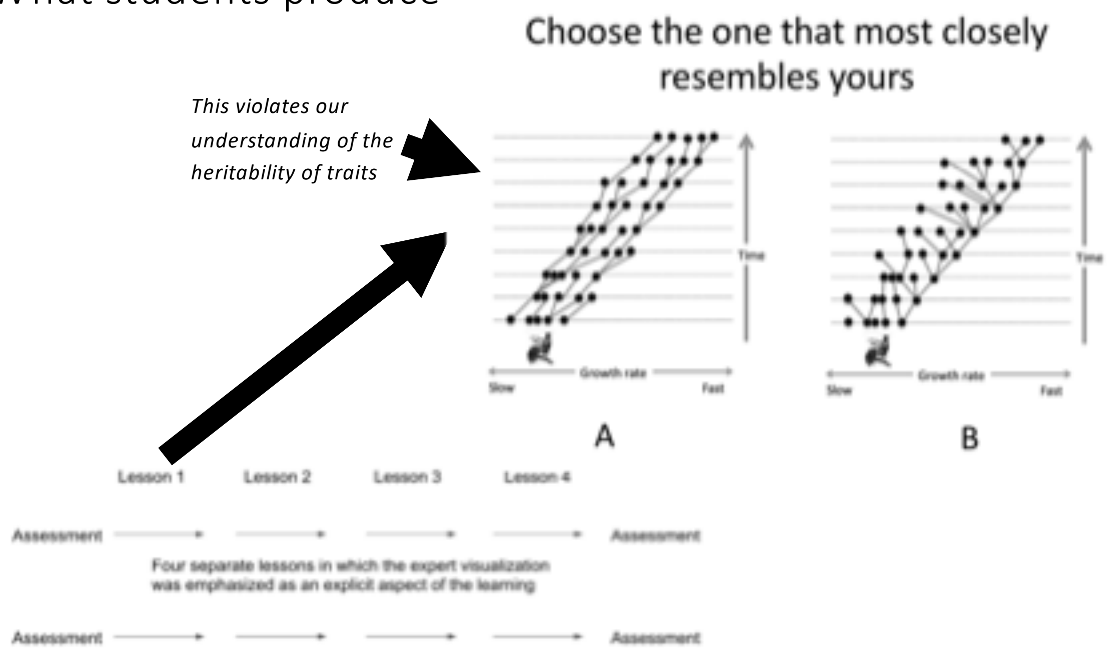
Domestication

Cognitive ability and brain size

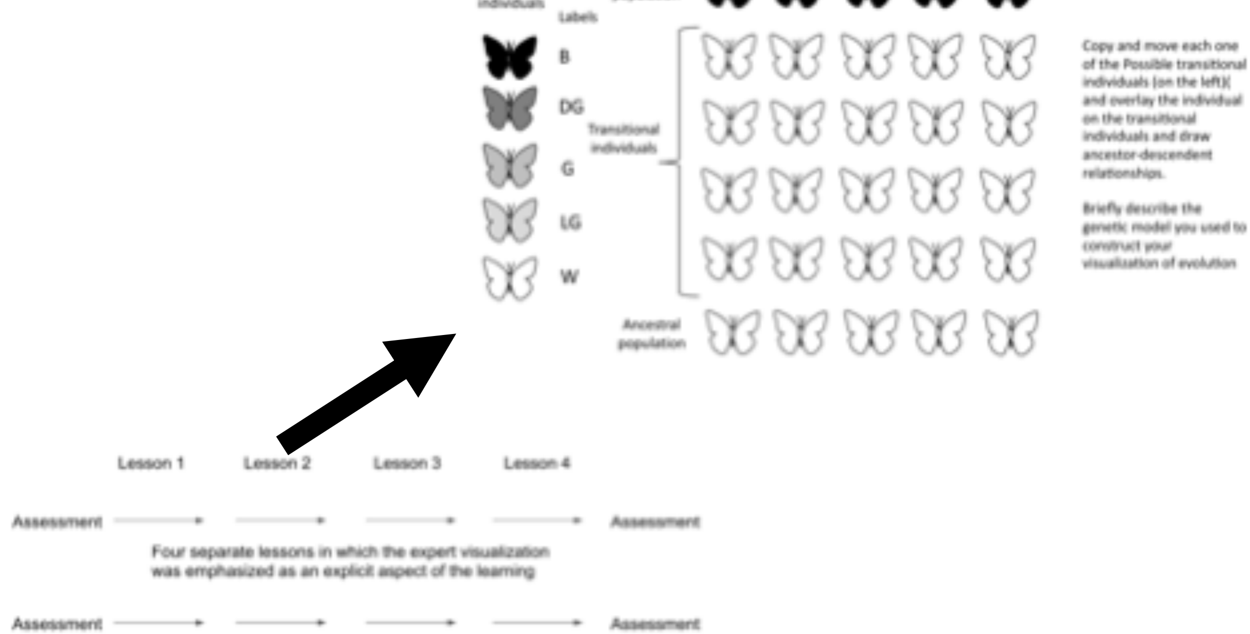


What students produce

This violates our understanding of the heritability of traits

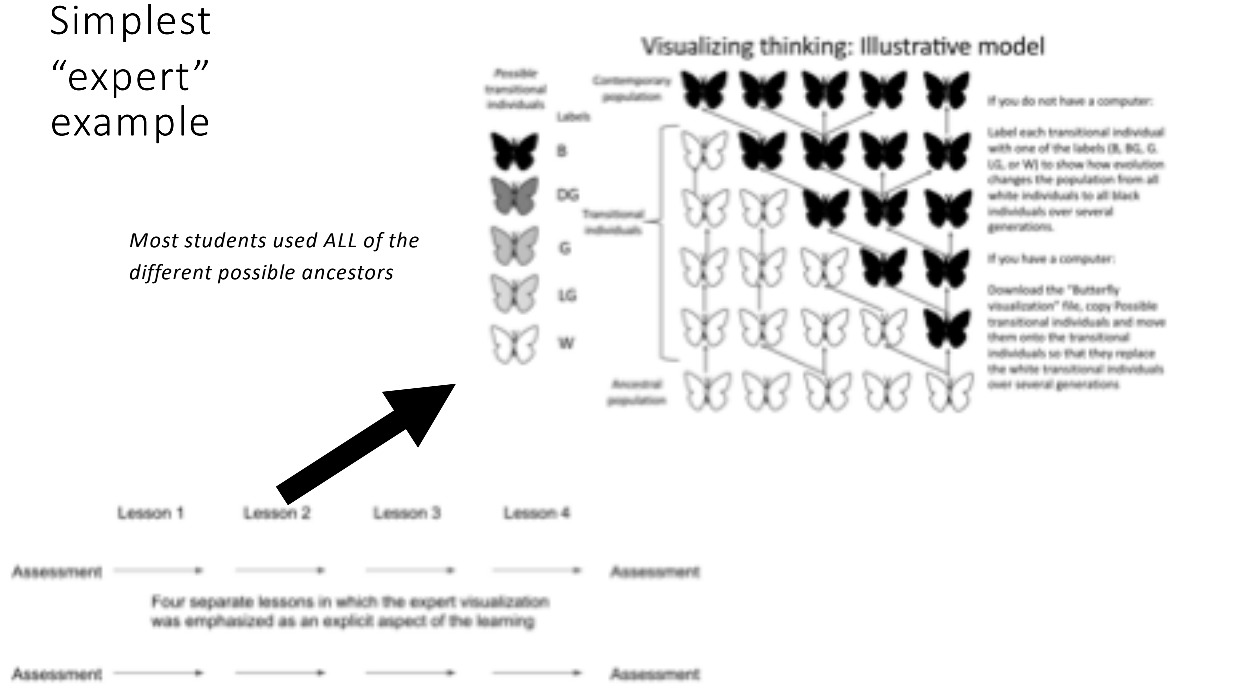


Example curriculum

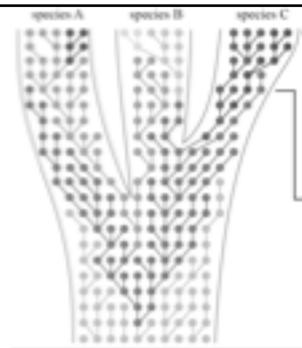


Simplest "expert" example

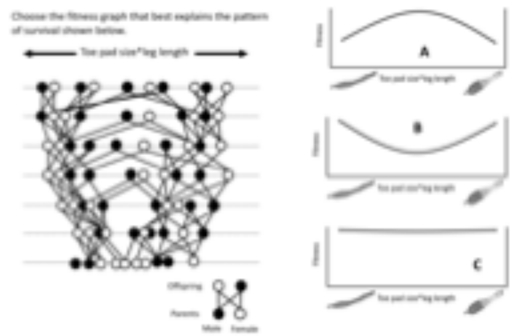
Most students used ALL of the different possible ancestors



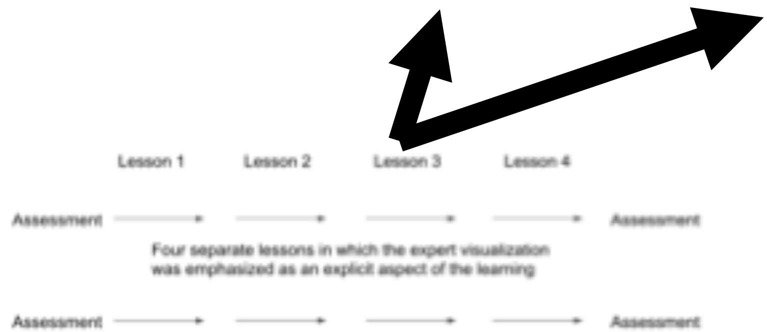
Example curriculum



Describe in writing your interpretation of the information in this tree

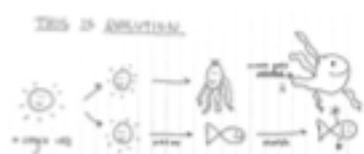


Three clicker questions similar to this one



Coding student answers

0 = no visualization



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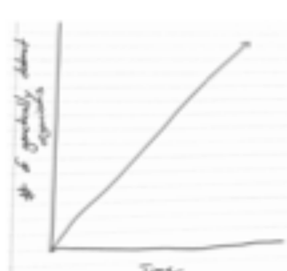
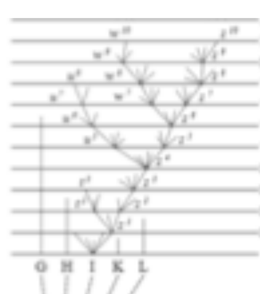


3 = graph



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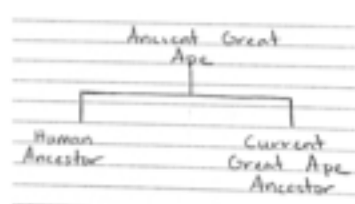
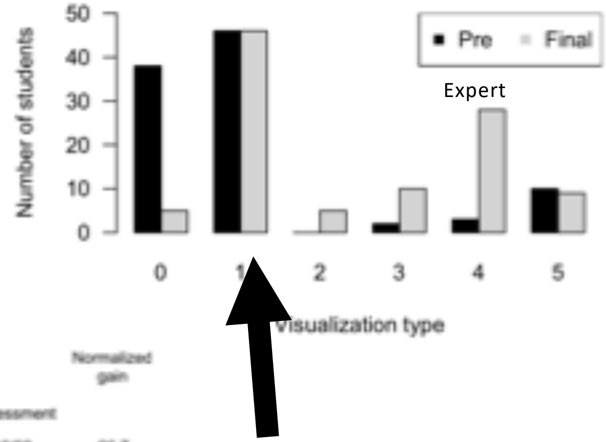


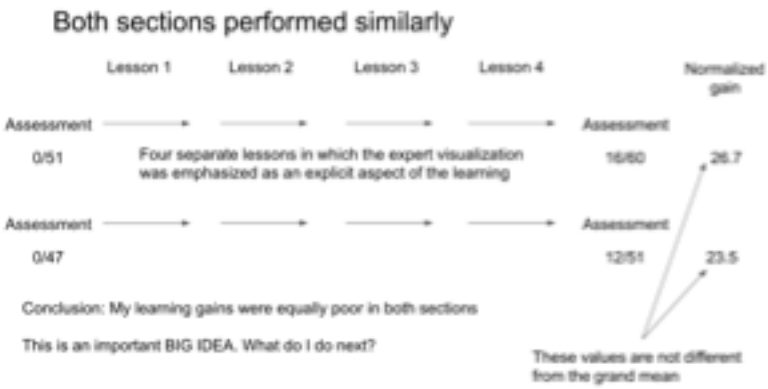
5 = tree

Results

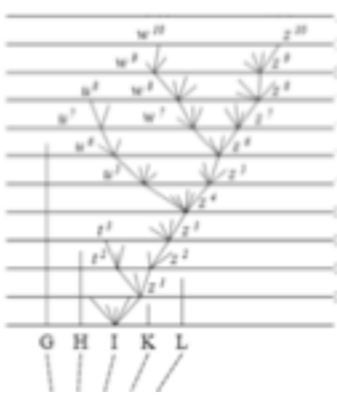


Expert

The progressive view of evolution is resilient



Possible revisions

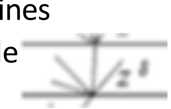


New formative assessment

Part 1: Describe the process depicted in Darwin's illustration of evolution.

Part 2: Answer the following questions

Why do you think Darwin drew multiple lines of different lengths emerging from a single point?



Why do you think Darwin drew lines with different lengths coming from each point?

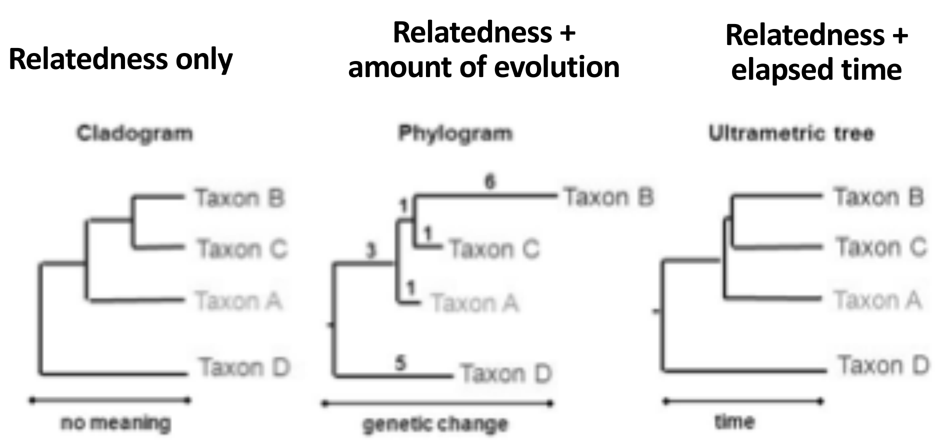
Why do you think Darwin included horizontal lines?

What is the meaning of a branch length?

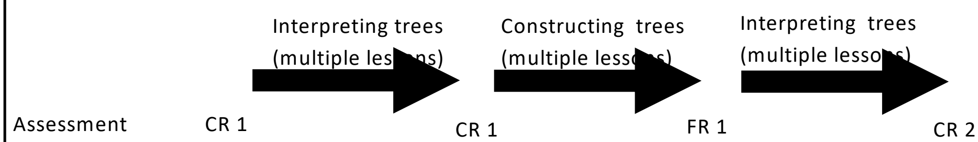
A key concept in evolution is deciphering phylogenetic information

A phylogenetic tree MAY contains THREE important pieces of information:

1) The relatedness of taxa
2) The amount of evolution along each "branch"
3) The relative time of origin of lineages



"Experiment"

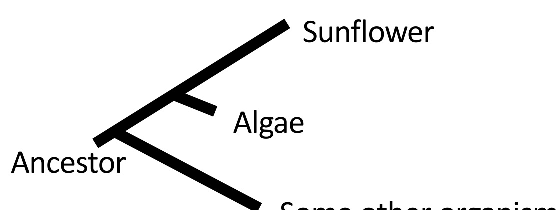


CR = Constructed (e.g. multiple choice) response

FR = Free response

CR 1

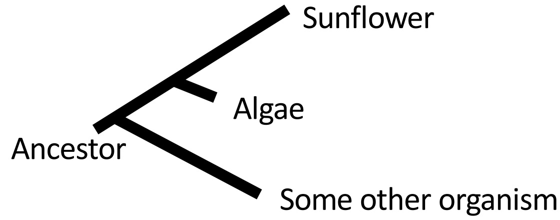
Which lineage has been evolving for the longest period of time?



A) Sunflower
B) Algae
C) Both have been evolving for the same amount of time
D) Need fossils to know for sure

Example

Which lineage has been evolving for the longest period of time?



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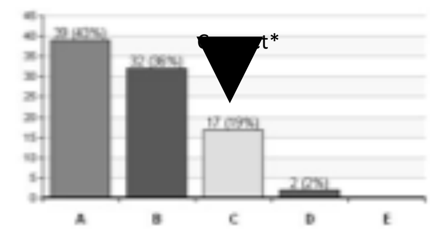
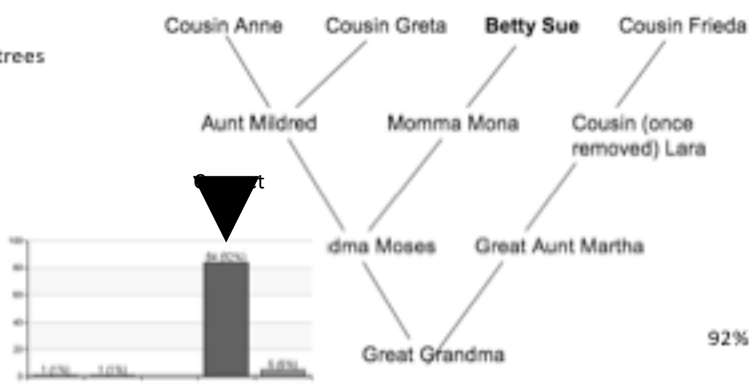


*-Indicates values is less than expected if students randomly chose an answer

Interpreting trees

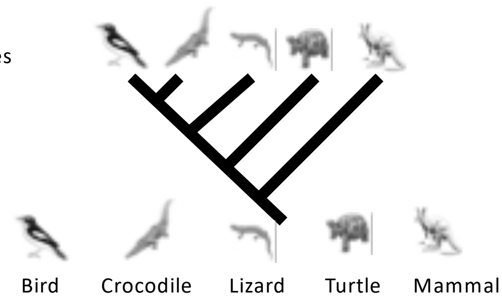


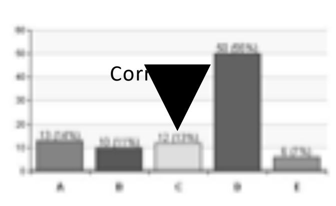
Example question for discussion of extracting information about relatedness

92% correct

Q5: Which cousin(s) is (are) most closely related to Betty Sue?
A) Cousin Anne
B) Cousin Greta
C) Cousin Greta and cousin Frieda are equally related to Betty Sue
D) Cousins Anne and cousin Greta are equally related to Betty Sue
E) Cousins Anne, Greta and Frieda are equally related to Betty Sue

Interpreting trees





Example question for discussion of extracting information about relatedness

Q4: Which taxon (taxa) is (are) most closely related to turtles?

A) Lizard

B) Mammal

C) Bird, crocodile and lizard are equally related to turtles

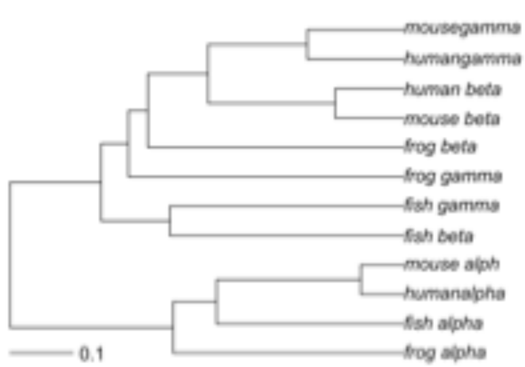
D) Lizard and mammal are equally related to turtles

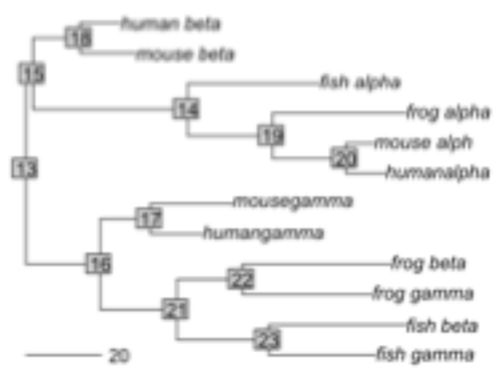
E) All species (bird, crocodile, lizard & mammal) are equally related to turtles

*-Indicates values is less than expected if students randomly chose an answer

Constructing trees

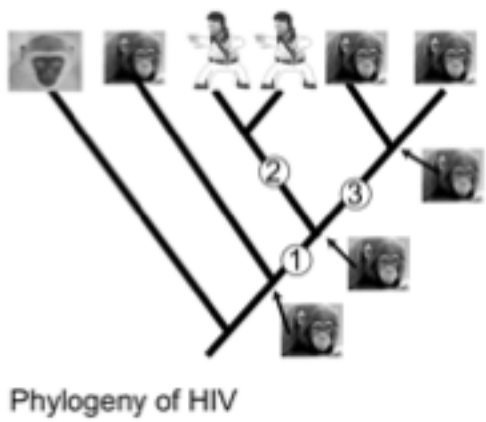
Students make these trees

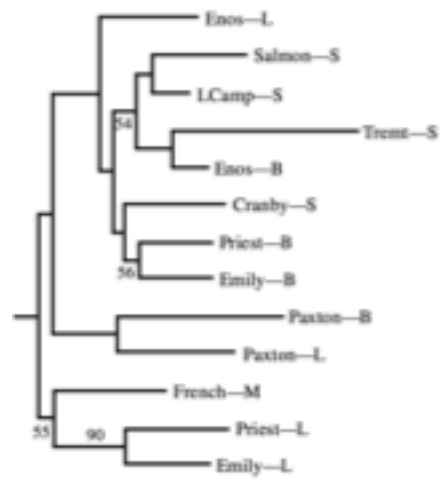




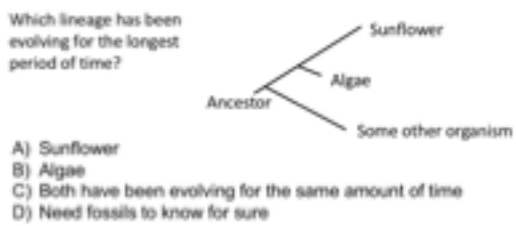
Free response question: What is the meaning of a branch length? An example of a branch length is the length of the horizontal lines from an ancestor (labeled with a blue box) and a descendant (labeled with letters, e.g. from ancestor 22 to frog gamma)

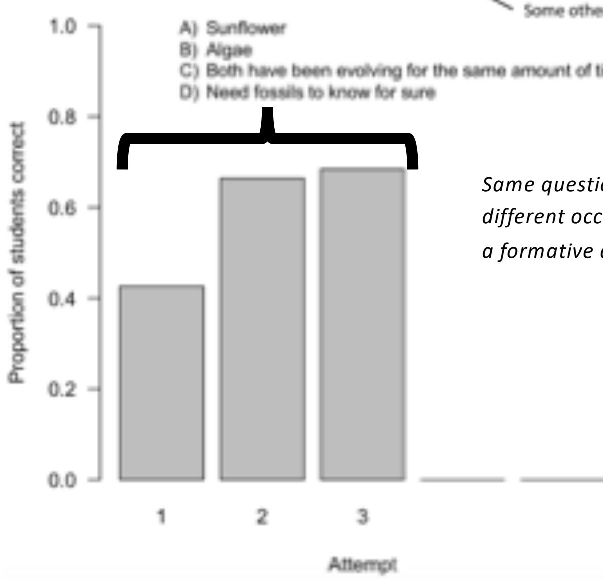
Interpreting trees: examples from their curriculum





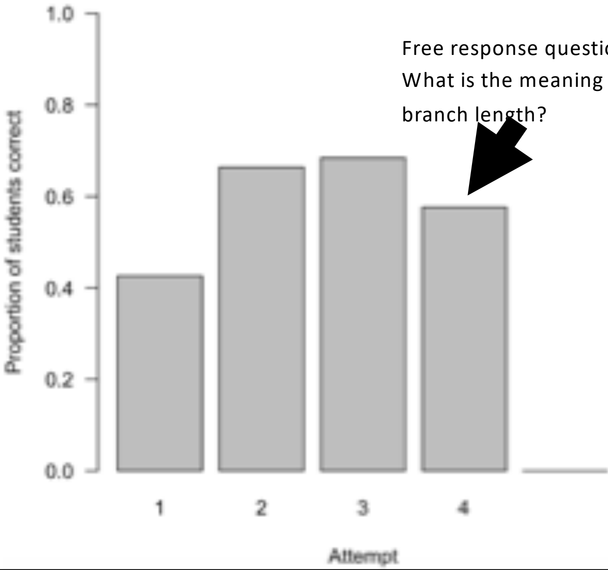
Results



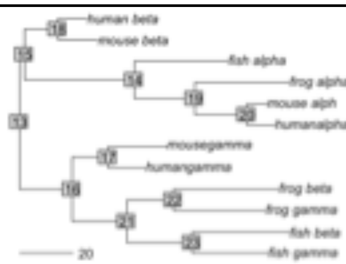


Same question asked on three different occasions (in class) as a formative assessment

Results

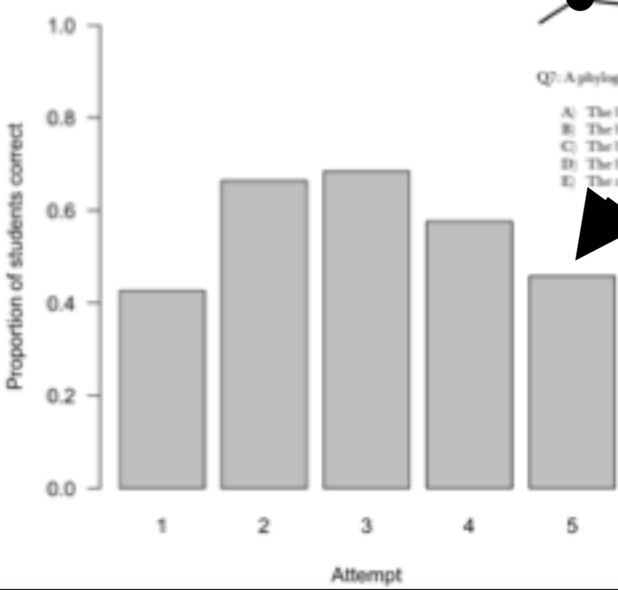


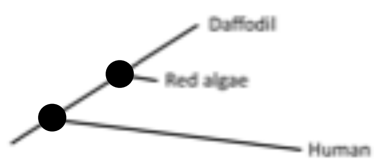
Free response question: What is the meaning of a branch length?



Example correct answer: *"Longer branch lengths show more change, and shorter branch lengths show less change from the ancestor."*

Results





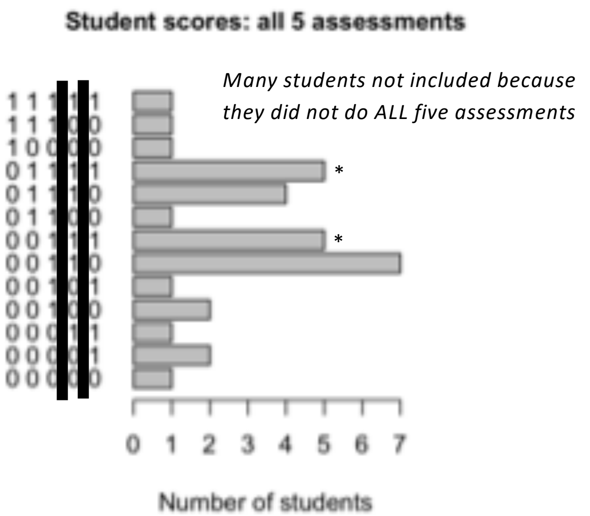
Q7: A phylogeny for three extant species. What is the meaning of the branch lengths?

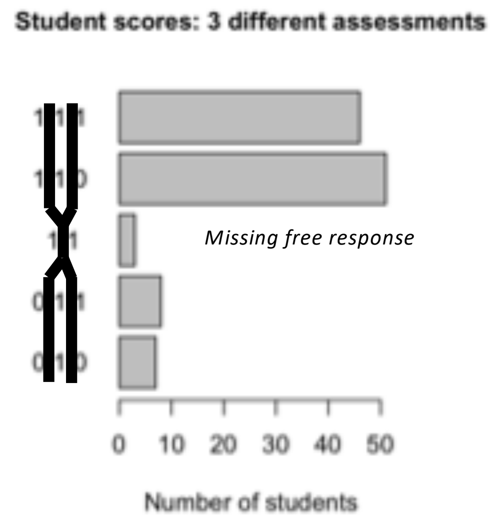
A) The branch lengths indicate time
B) The branch lengths are the number of changes from an ancestral species to a descendent species
C) The branch lengths are informative about the relatedness of two taxa
D) The branch lengths are informative when there is fossil information
E) The relative time elapsed across different parts of the tree

These responses generated by students

Almost NO gain from pre-assessment
Normalized gain = 0.054

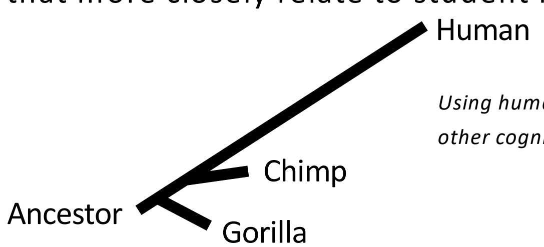
Correct answer patterns





What to do?

- Have students construct trees with branch length information by hand (they used a computer program)
- Use examples that more closely relate to student interests
  - Example



Using humans tends to impose other cognitive challenges

- Get suggestions from my peers

Some potential confounding issues

- Students are distracted and may not invest the necessary time and effort into learning
  - Self-reported data: 74% of students are on their phones at least once during class (an underestimate)
  - Most students do not enact effective learning strategies outside of class