Appendix

Examples of Retention and Transfer Questions

Classification of questions as retention or transfer depended on the question's relation to the particular content that was presented in class. As an illustrative example of the type of active learning in the classroom and how exam questions were categorized in relation to context, here we briefly describe the components of the lesson on sexual selection (adapted from Kalinowski et al., 2013) followed by the corresponding transfer and retention questions that appeared on the exam. In the class lesson, the instructor introduced the hypothesis that male peacocks have elaborate trains because females prefer to mate with males that have elaborate trains. Students were shown two figures: one showing a positive correlation between number of eyespots on train and number of matings and the other showing positive correlation between brightness of eyespots and number of matings. In small groups, students discussed whether these data definitely supported the hypothesis and submitted a response (via an electronic polling system). The instructor then led a discussion about causation and correlation, illustrating that correlative data cannot fully support a hypothesis about causation. Students were asked to design a study that would be able to illustrate causation (and responded via the electronic system). Afterwards, the instructor told the students about an experimental design that a researcher used, and students had to sketch results that would support the hypothesis (using a figure with given axes). Then students were shown the actual data and asked to compare the data to their predictions and decide whether the data supported or refuted the hypothesis. After further discussion, the instructor reminded the students of the three principles of natural selection discussed in a prior class and showed them how sexual selection is a special case of natural selection because all three principles apply to the example of peacock trains.

Corresponding Retention Question

The following question required recalling a principle that was explicitly stated at the end of the classroom lesson described above, and accordingly only requires retention of class content.

Which of the following statements about sexual selection and natural selection is true?

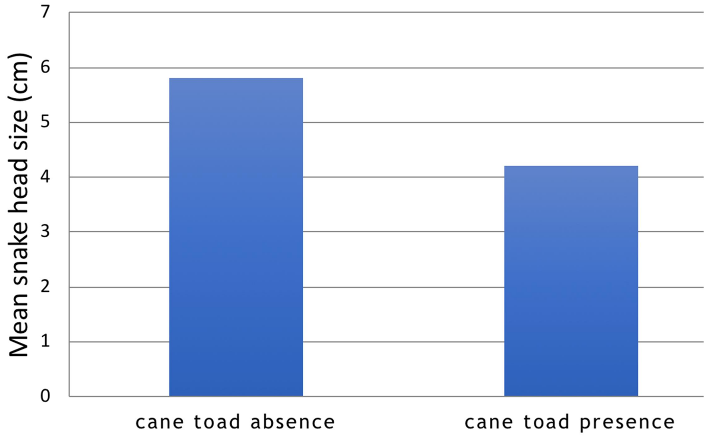
A. Sexual selection is a special case of natural selection.
B. Sexual selection and natural selection always oppose each other.
C. Sexual selection requires differential reproduction whereas natural selection requires differential survival
D. Sexual selection affects reproductive organs and natural selection affects everything else.

Corresponding Transfer Questions

1. To correctly answer the next question, students must evaluate data displayed in a graph and interpret those data to draw a conclusion about a hypothesis. These processes were practiced in the classroom lesson, but the question focuses on data reflecting the more general principle (natural selection) than the sexual-selection data analyzed in the classroom lesson, the contextual elements have changed (more than one species interacting, different species present, changing context for the target species) and the question is different from that analyzed in class. Thus, transfer from the lesson is required.

The invasive cane toad was introduced to Australia in the 1930s. The toads are extremely poisonous to red-bellied black snakes, and there was some concern that the snake population might be decimated. However, the snakes and toads seem to be co-existing.

Imagine a biologist began investigating the situation by surveying red-bellied black snakes in areas with and without cane toads and found one major difference between the two populations.



The results are depicted in the hypothetical graph below.

Which of the following scenarios is most likely given the data?

A. Where cane toads are present, red-bellied black snakes evolved a tolerance to cane toad toxins that allowed them to survive and reproduce.
B. Where cane toads are present, red-bellied black snakes with large heads died while those with small heads survived and reproduced.
C. The presence of cane toads caused mutations that resulted in smaller heads.
D. The red-bellied black snaked mutated in response to the cane toads so that they could tolerate cane toad toxins.

2. This question requires analyzing data and integrating multiple concepts: (a) the trait increases lifetime reproduction even though it decreases survival and (b) adaptations should increase in frequency within a population. In the classroom lesson, students discussed a similar idea but with a different species (peacocks) and focusing on the phentotype. The question requires transfer of the class lesson to integration of multiple concepts, a different organismal context, and a focus at the genotype level.

Orange sulfur butterflies (*Colias eurytheme*) typically live up to 4 weeks as adults and females lay hundreds of eggs. Imagine a mutation that causes females to produces eggs more quickly. However, producing so many eggs requires a lot of resources and the mutation also decreases lifespan. A researcher measured the number of eggs produced each week by females with the original and the mutated allele.

	Average # of eggs produced	
Week	Original allele	Mutated allele
1	75	100
2	50	75
3	50	75
4	25	0 (dead)

Which of the following is the best prediction given this data?

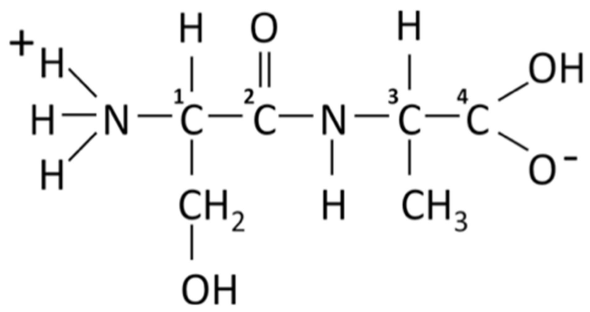
A. The mutated allele will decrease in frequency because it reduces fitness.
B. The mutated allele will decrease in frequency because it reduces survival.
C. The mutated allele will increase in frequency because it will be favored by mates.

D. The mutated allele will increase in frequency because it increases lifetime reproduction.

Protein-Structure Lesson with Retention Questions

Retention questions could also be more “process-oriented” such that the answer depended on analyzing or interpreting information given in the question (as did the above transfer questions). In the lesson students learned about protein structure as well as how mutations can change structure and function in the context of a scenario about Type 1 diabetes. The particular mutation led to a single AA change in the insulin receptor that resulted in poor binding of insulin to its receptor. To understand this, students became familiar with AA structure by examining individual AAs, including identifying the N and C termini and which part of the AA was most important to focus on when it is part of a polypeptide. Students drew tripeptides and practiced identifying the alpha carbons and the peptide bonds, but had not worked with or seen the particular dipeptide on the exam during class. The following are questions classified as *retention* items because the students directly practiced identifying the carbons and bonds in class.

Use the following image to answer questions 17-19. Note that some of the carbons are numbered.



18. Look at the numbered carbons. Which is/are the alpha carbon(s)?
    a. 1
    b. 1 and 2
    c. 1 and 3
    d. 1, 2, 3, and 4

19. Which of the following is a peptide bond(s)?
    a. The bond to the left of carbon 1
    b. The bond between carbons 1 and 2
    c. The bond to the right of carbon 2
    d. The bond to the left of carbon 4

Reference

Kalinowski, S. T., Leonard, M. J., Andrews, T. M., & Litt, A. R. (2013). Six classroom exercises to teach natural selection to undergraduate biology students. *CBE—Life Sciences Education, 12*(3), 483–493. https://doi.org/10.1187/cbe-12-06-0070