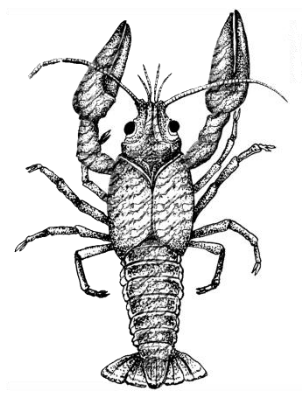
EvoDevoCI:
Concept Inventory of Evolutionary Developmental Biology

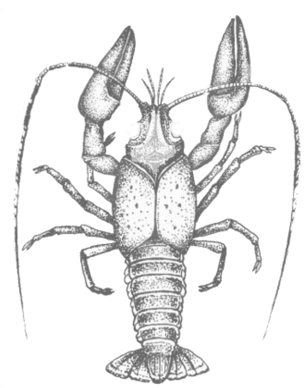
Using the information provided below, please answer the following questions:

Crayfish

Approximately 10,000 years ago a population of crayfish entered a cave. Though initially indistinguishable from crayfish that live on the surface, today the cave crayfish do not develop eyes and have *longer antennae that provide an improved sense of smell*. By manipulating their embryos in the lab, it is possible to produce cave crayfish with eyes. When the cave crayfish with and without eyes are placed into a dark, cave environment, they show no difference in survival and reproductive success.

Surface	**Cave**
Eyes	No Eyes
Short Antennae	Long Antennae





1. When investigating crayfish genes that play a role in the development of the sensory nervous system, it is discovered that a gene known as *sense1* is active at higher levels in the embryos of cave crayfish than in embryos of surface crayfish. When the level of activity of *sense1* is artificially increased in embryos of surface crayfish they develop without eyes and with long antennae.

   Of the following hypotheses, which best explains how cave crayfish have lost their eyes?

   A. In the cave population, the *sense1* gene appeared, causing crayfish to lose their eyes and improve their sense of smell.

   B. In the cave population, mutations in *sense1* that increased the activity of *sense1* appeared repeatedly and more frequently over time.

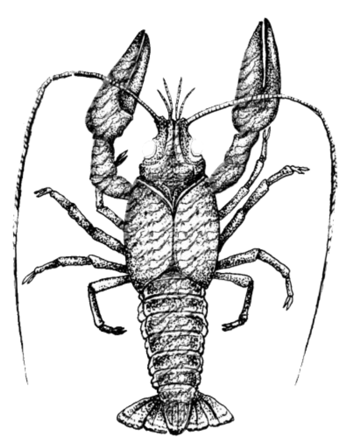
   C. In the cave population, a mutation that increased the activity of *sense1* became more frequent in cave crayfish over time because it also improved sense of smell.

   D. In the cave population, the crayfish lost their eyes over time because they did not use them.

Surface with increased *sense1* activity

No Eyes

Long Antennae



2. A third population of crayfish lives in a very muddy stream. Like the cave form, these crayfish have longer antennae, but unlike the cave form, these muddy stream-dwelling crayfish have retained their eyes.

   Of the following hypotheses, which best explains how crayfish in the muddy stream have long antennae?

   A. In many crayfish individuals in the muddy stream, a mutation occurred that increased the length of antennae, but did not increase the activity of *sense1*.

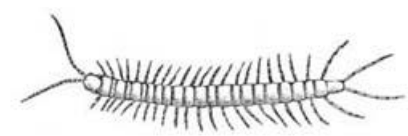
   B. Among crayfish in the muddy stream, those that possessed a mutation that increased the length of antennae, but not the activity of *sense1*, had greater reproductive success.

   C. Among crayfish in the muddy stream, those with *sense1* had greater reproductive success than those without *sense1*.

   D. Crayfish in the muddy stream are more closely related to the cave crayfish than they are to the surface crayfish.

Centipedes

Centipede species vary in the number of leg-bearing segments, from as few as 5 to as many as 125, but all centipedes possess an odd number of leg-bearing segments, and thus an odd number of pairs of legs. By manipulating leg-bearing segment number, it has been determined that there is no difference in survival and reproductive success between individuals with even and odd numbers of pairs of legs.



This centipede has an odd number of leg-bearing segments and thus an odd number of leg pairs.

3. If there is no difference in reproductive success between individuals having an even versus an odd number of leg pairs, why don't any centipedes have even numbers of leg pairs?

   Of the following, choose the best hypothesis.

   A. Centipedes do not need even numbers of leg pairs if odd pairs are sufficient for survival; therefore they choose to have an odd number of leg pairs.

   B. Centipedes with even numbers of leg pairs do not occur because of the way segments are added during development.

   C. Centipedes do not have the gene that causes an even number of leg pairs to form during development.

   D. Centipedes with an even number of leg pairs are more likely to be eaten by a predator.

Minnows

Minnows belong to a group of fishes known for their diverse patterns of pigmentation. For example, some species are striped while others are spotted. Among ten closely related species of minnow, seven exhibit a stripe pattern and live in lakes with predators. The remaining three species exhibit a spot pattern and live in lakes with no predators. The evolutionary relationships among the ten species suggest that the spot pattern evolved independently in these three species.

The protein product of the *spotty* gene is a receptor for molecules that cells use to communicate during development. When scientists remove the *spotty* gene completely from the genome of species that normally possess a stripe pattern they instead exhibit a spot pattern similar to the naturally occurring spot pattern, but also exhibit skeletal defects.

Fish of a striped species in which the *spotty* gene has been removed (skeletal defects not shown)

The *spotty* gene is more active in all seven of the striped species than in any of the three spotted species. In the lab, however, mutations in several other genes also result in a spot pattern similar to the naturally occurring spot pattern.

4. Of the following hypotheses, which is the most plausible scenario for how the spot pattern arose in nature?
   A. The pattern arose when the environment caused some minnows to develop with a spot pattern, which was then passed on to offspring.
   B. The pattern arose when the *spotty* gene was lost, causing a spot pattern that resulted in increased reproductive success.
   C. Mutations in one or a few genes lowered the activity of *spotty*, causing a spot pattern that increased reproductive success.
   D. Mutations in many genes must have lowered the activity of *spotty*, each causing a slightly closer resemblance to the spot pattern and each increasing reproductive success.

5. In mammals, *spotty* plays a similar role in pigmentation, but is also required for the proper development of the nerves that control the digestive tract. The proteins produced by the *spotty* gene in fish and mammals are almost identical in functionally significant amino acids. If the proteins are so similar, which of the following hypotheses best explains how it is that the Spotty protein is needed for proper gut function in mammals, but not fish?
   A. Mammals have more complex guts than fish, requiring additional proteins.
   B. In fish, *spotty*'s effect on gut function has not led to differences in survival or reproductive success.
   C. In mammals, *spotty* is active in different cells at different times than it is in fish.
   D. Mammals occupy different environments than fish, requiring that different genes play a role in gut function.

6. In the minnow species, genetic experiments have shown that in cases where the activity of *spotty* has changed due to genetic changes, the change has not occurred in the *spotty* gene, either in the regions that code for the spotty protein or the regions that control *spotty* activity.

   Of the following hypotheses, which best explains how it is that the activity of *spotty* differs between the different minnow pattern types?

   A. The three species with the spot pattern possess mutations in other genes that lower the activity of *spotty*.

   B. The three species with the spot pattern possess mutations in *spotty* that lower the activity of the gene.

   C. The three species with the spot pattern possess mutations in HOX genes that lower the activity of *spotty*.

   D. The three species with the spot pattern possess mutations that lower the activity of *spotty* because these mutations increased reproductive success in the presence of predators.

7. Of the following hypotheses, which best explains why *spotty*, and not another gene known to cause a spot pattern when disrupted, appears to be involved in all three instances in which the spot pattern evolved?

   A. The common ancestor of all three species possessed a mutation that lowered the activity of *spotty*.

   B. Mutations that lowered the activity of *spotty* had fewer deleterious effects on other developmental processes than the other mutations that can also cause the spot pattern.

   C. In each of the three species, the minnows inhabited a lake free of predators, causing *spotty* to be affected, but not the other genes involved in pigmentation pattern.

   D. Because during evolution, mutations that lower the activity of *spotty* occur more frequently than mutations affecting the activity of the other genes involved in pigmentation pattern.

Lizards

Two populations of lizards of the same species (“Species A”) exhibit strikingly different skin coloration as the result of a history of predation by birds. The green lizards are found in wetland regions and the brown lizards are found in more arid regions. When brown lizards are placed in a wetland environment and allowed to reproduce, in the next generation their offspring are green. Alternatively, when green lizards are placed in an arid environment, in the next generation their offspring are brown. The results of these experiments are summarized in the table below.

Parental Skin Color	**Experimental Environment**	**Offspring Skin Color**
Brown	Arid	Brown
Brown	Wetland	Green
Green	Arid	Brown
Green	Wetland	Green

8. Of the following hypotheses, which best explains how it is possible for this population of lizards to change their skin color in one generation?
   A. These lizards possess different alleles for skin color based on the environments they occupy.
   B. Lizard mothers sense the change in environment and choose to change the color of their offspring.
   C. Only offspring with protective coloration survive.
   D. Skin color is determined by environmental factors.

9. Of the following hypotheses, which best explains how these lizards gained the ability to change skin color in response to the environment?
   A. Lizards that had an ability to change their skin color in response to the environment during development had greater reproductive success than others.
   B. A gene appeared in the genome of an individual lizard that gave it the ability to change skin color in response to the environment, increasing its reproductive success.
   C. There has not been enough predation in their environment to make their skin color constant.
   D. The appropriate genotype for skin color will always appear in individuals depending on the environment.

Another species of lizard ("Species B") that only inhabits wetlands is green in color. When placed in an arid environment, the immediate offspring and subsequent generations remain green.

10. Of the following hypotheses, which best explains how Species A gained the ability to change skin color while Species B did not?
   A. Unlike Species A, Species B cannot change color because offspring were unable to inherit this ability from parents.
   B. In response to predation, Species B evolved green coloration, while Species A evolved the ability to change skin color.
   C. A gene appeared in the genome of an individual of Species A that gave it the ability to change skin color, but this did not occur in Species B.
   D. In the past, Species B has experienced more predation than Species A, causing it to evolve.

A study conducted over several years examined the relationship between habitat and leg length. In the study, lizards from a treeless habitat were forced to live in small trees using a cage system, while a control group was allowed to remain on the ground. Only after many generations, it was discovered that members of the tree group had slightly shorter legs than the control group, even when later generations were raised on the ground. This observation was consistent with the observation that short legs allow for greater maneuverability on branches, while long legs allow for greater speed on the ground.

11. Of the following hypotheses, which best explains how it is that living in trees resulted in shortened legs?
   A. The change occurred because new genes appeared that resulted in the formation of shorter legs and increased reproductive success.
   B. The change occurred because there was heritable variation in the process of leg development.
   C. The change occurred because these lizards have evolved the ability to alter their leg length in response to the environment.
   D. The change occurred because the tree environment induced shortened legs, which were then inherited.

Appendix 2. Identity of correct responses and the conceptual difficulties upon which distractors are based.

Item	Responses	Conceptual Difficulty	Item	Responses	Conceptual Difficulty
1	A	ED2	7	A	ED4
CC4	B	ED1	CC3	B	Correct
	C	Correct		C	EV9
	D	EV1		D	DV1[5]
2	A	EV4	8	A	EV2
CC3	B	Correct	CC5	B	CB3
	C	ED2		C	DV1[6]
	D	ED4		D	Correct
3	A	CB1	9	A	Correct
CC4	B	Correct	CC6	B	ED3
	C	ED2		C	EV3
	D	DV1[1]		D	CB2
4	A	EV2	10	A	EV2
CC1	B	ED2	CC5	B	Correct
	C	Correct		C	ED3
	D	EV6[2]		D	EV3
5	A	DV2	11	A	ED3
CC2	B	EV3	CC6	B	Correct
	C	Correct		C	DV1[7]
	D	DV1		D	EV2
6	A	Correct			
CC2	B	ED1[3]			
	C	DV5			
	D	DV1[4]			

[1]This distractor additionally contradicts the scenario by suggesting differences in fitness between centipedes with odd versus even numbers of leg pairs.

[2]While it is certainly possible that the change is due to mutations in “many genes”, this distractor includes “must have” in order to imply an exclusive commitment to this idea (EV6).

[3]This distractor additionally contradicts the stem.

[4]This distractor additionally contradicts the scenario by suggesting increased fitness of the spot pattern in the presence rather than in the absence of predators.

[5]Although examples of mutational “hotspots” do exist in the literature, it is not at all clear (as yet, anyway) that this is a general mechanism of evolutionary change.

[6]While this distractor is a viable ultimate explanation for the evolution of the plastic response, it does not provide an adequate explanation for how skin color could change in a single generation.

[7]The possibility that leg length is plastic is additionally ruled out by the scenario ("…even when later generations are raised on the ground").