Session 7: Evolution of Vertebrates

Overview:
In this session, we dig more deeply into the evolution of the complex behaviors and patterning found in vertebrates. We begin with an whiteboard video which investigates why sexual reproduction provides an evolutionary advantage over asexual reproduction, in most cases. In the second video, we wonder why you jump when someone startles you. Melina Hale explains how her research into the startle response in fish may help us to understand the evolution of neural circuits in vertebrates. And in the last video, Neil Shubin explains how studying the expression of hox genes in fish and mice may help to explain the evolution of limb development from fish, to early tetrapods like Tiktaalik, to modern mice and humans.

First video:
Title: Sexual Versus Asexual Reproduction

Questions for Part1:

1. The queen bee makes the decision whether to fertilize an egg. Both fertilized and unfertilized eggs produce viable offspring. Bees have
    a. Only sexual reproduction.
    b. Only asexual reproduction.
    c. Developmental problems when the egg is not fertilized.
    d. Both sexual and asexual reproduction.
    e. Both C and D are correct.

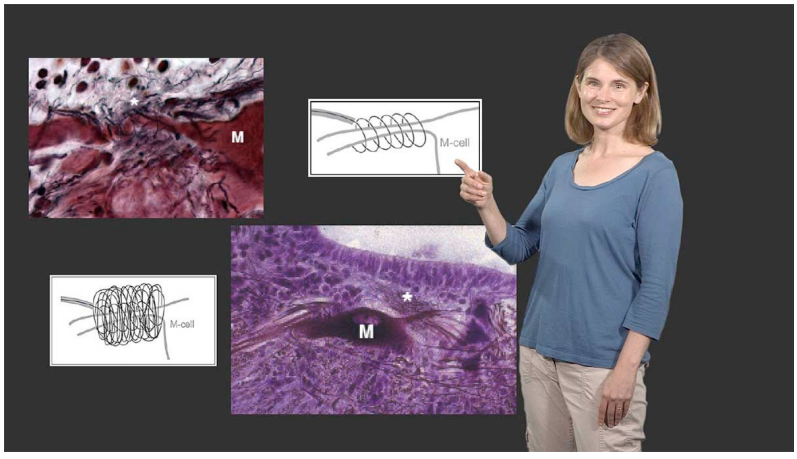
2. During meiosis, which of the following steps can introduce genetic diversity? Choose all of the answers that apply.
    a. Fertilization.
    b. Homologous recombination.
    c. Independent assortment.
    d. Gametogenesis.
    e. DNA synthesis.

3. Which of the following is not an example of asexual reproduction?
    a. Budding
    b. External fertilization
    c. Fragmentation
    d. Parthenogenesis (reproduction from an ovum without fertilization)
    e. Regeneration from a fragment

4. Compare and contrast sexual and asexual reproduction. Briefly explain the advantages/disadvantages of each method of reproduction.

5. Hermaphrodites have both male and female reproductive organs in a single animal. They can produce both egg and sperm and self-fertilize. How does this differ from asexual reproduction?

Second Part:
Title: Neural Circuits and How They Evolve: A Startling Example!
Speaker: Melina Hale



Questions for Part 2:

1. Scientists believe that the startle response is conserved from fish to mammals because
    a. both fish and mammals evolved from a common ancestor.
    b. fish and mammals share the same number of neurons.
    c. it is a fundamental behavior used by both fish and animals to avoid predators.
    d. fish are the predecessors of mammals.
    e. fish and mammals share the same developmental stages.

2. Which of the following are necessary for the C-startle response in fish?
    a. Absence of Mauthner cells.
    b. Activation of Mauthner cells.
    c. Inhibition of Mauthner cells.
    d. Both Activation and Inhibition of Mauthner cells.
    e. Absence of cap.

For questions 3-5, determine if the statement is true or false.

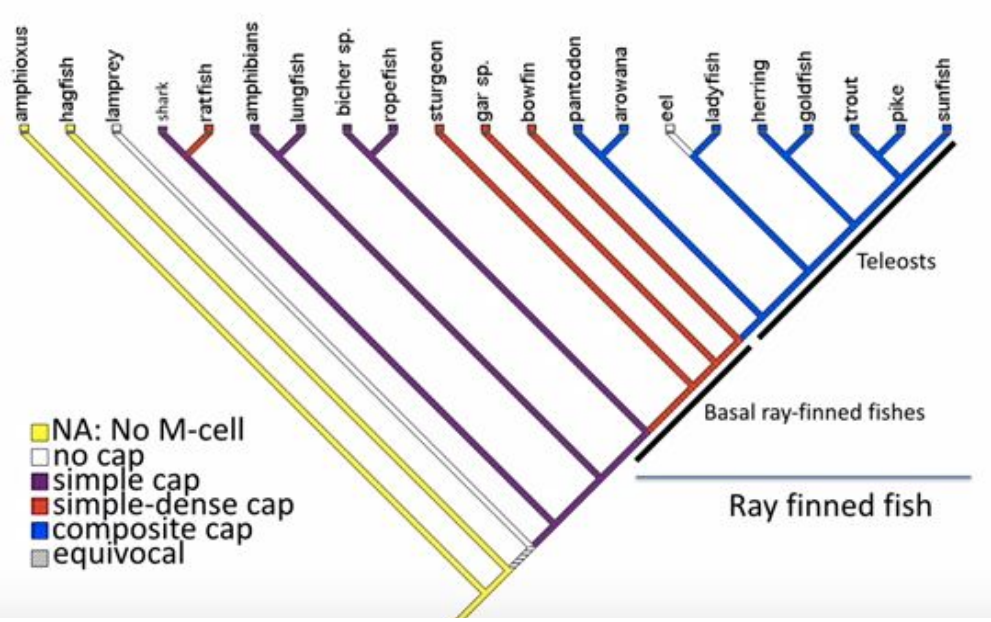
3. Activation of the left-hemisphere Mauthner cell in zebrafish would activate contraction of muscle cells in the right hemisphere.

4. Scientists have been able to localize complex behaviors (e.g. talking) with areas in the brain.

5. Fish species that have Mauthner cells show similar C-shaped startle responses.

6. Provide two reasons why the startle response is a good example to study the evolution of complex behaviours.

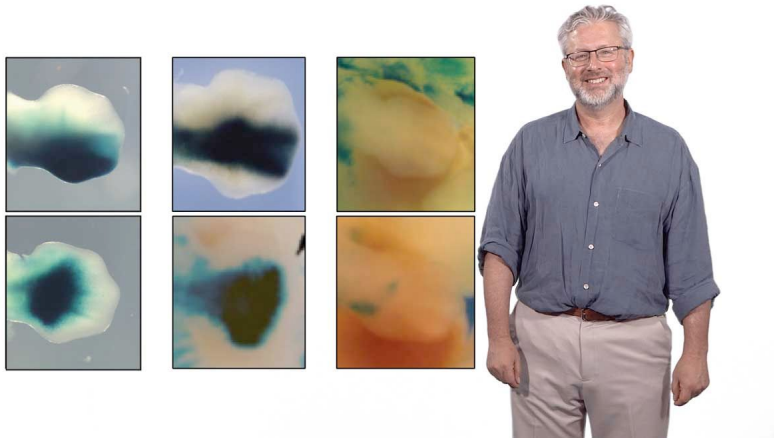
7. The phylogenetic tree of the evolution of Mauthner cells is shown below.



a. Briefly describe the steps in the evolution of Mauthner cells in fish.

b. Mauthner cells have not been observed in mammals, however, they still have a startle response. Propose an hypothesis that could help explain this observation.

Third video:
Title: The Evolution of Limbs from Fins
Speaker: Neil Shubin



Questions for Part 3:

1. What did scientists observe when they compared Hox genes between distantly related species? Choose all of the answers that apply.
    a. Conservation of early stage enhancers.
    b. Conservation of late stage enhancers.
    c. Protein sequence conservation.
    d. Intronic sequence conservation.
    e. Scientists did not observe any similarities among species.

For questions 2-4, determine if the statement is true or false.

2. The study of fossils and genes can help scientists to identify possible links between species.

3. The development of limbs in fish and humans is similar.

4. Hox genes are only activated during early stages of development.

5. Briefly explain how expression of Hox genes generates the appendages observed in limbs.

6. Noggin is a protein involved in the differentiation of nerve cells. Cells in the region of the embryo that expresses noggin will start to differentiate into neural cells. This locks in the fate of the cells.
    a. When comparing development between species, scientists study the non-coding and coding regions of a gene. Why?

    b. Some cells that undergo the same early developmental stages as neural cells, ultimately do not become neurons. For example, melanocytes (pigment producing cells) are derived from the neural lineage, but they differentiate into melanocytes later in development. Would you expect the same proteins that regulate the differentiation of neurons to be present in melanocytes? Briefly explain.

7. What experiments led scientists to propose the importance of Hox genes in the development of vertebrate limbs? Briefly explain.

Answers for Session 7:

Questions for Part1:

1. The queen bee makes the decision whether to fertilize an egg. Both fertilized and unfertilized eggs produce viable offspring. Bees have
    a. Only sexual reproduction.
    b. Only asexual reproduction.
    c. Developmental problems when the egg is not fertilized.
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2. During meiosis, which of the following steps can introduce genetic diversity? Choose all of the answers that apply.
    a. **Fertilization.**
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3. Which of the following is not an example of asexual reproduction?
    a. Budding
    b. **External fertilization**
    c. Fragmentation
    d. Parthenogenesis (reproduction from an ovum without fertilization)
    e. Regeneration from a fragment

4. Compare and contrast sexual and asexual reproduction. Briefly explain the advantages/disadvantages of each method of reproduction.
    Sexual reproduction increases the genetic diversity of a population allowing it to evolve and adapt to changing environmental conditions. Sexual reproduction often requires a large time and energy commitment.

    Asexual reproduction produces offspring that are genetically identical to their parents. It does not allow harmful alleles to be segregated separately from beneficial alleles. Changes to the genome occur only by random mutation which is very slow. However, asexual reproduction is not as energy or time intensive.

5. Hermaphrodites have both male and female reproductive organs in a single animal. They can produce both egg and sperm and self-fertilize. How does this differ from asexual reproduction?
    Both forms of reproduction allow an individual to produce offspring without mating. However, because hermaphrodites produce eggs and sperm, they can, and frequently do, mate with other individuals. This increases the genetic diversity of the population.

Questions for Part 2:

1. Scientists believe that the startle response is conserved from fish to mammals because
    a. both fish and mammals evolved from a common ancestor.
    b. fish and mammals share the same number of neurons.
    c. **it is a fundamental behavior used by both fish and animals to avoid predators.**
    d. fish are the predecessors of mammals.
    e. fish and mammals share the same developmental stages.

2. Which of the following are necessary for the C-startle response in fish?
    a. Absence of Mauthner cells.
    b. Activation of Mauthner cells.
    c. Inhibition of Mauthner cells.
    d. **Both Activation and Inhibition of Mauthner cells.**
    e. Absence of cap.

For questions 3-5, determine if the statement is true or false.

3. Activation of the left-hemisphere Mauthner cell in zebrafish would activate contraction of muscle cells in the right hemisphere.
   True.

4. Scientists have been able to localize complex behaviors (e.g. talking) with areas in the brain.
   True.

5. Fish species that have Mauthner cells show similar C-shaped startle responses.
   False.

6. Provide two reasons why the startle response is a good example to study the evolution of complex behaviours.
    a. **It is conserved across taxa.**
    b. **Scientists can use modern organisms with relatively simple circuits to study the startle response.**

7. The phylogenetic tree of the evolution of Mauthner cells is shown below.
    a. Briefly describe the steps in the evolution of Mauthner cells in fish.
       The earliest fish (yellow), which were not actually vertebrates, did not have Mauthner cells. Lampreys (white) which diverged off of the tree next, have Mauthner cells but do not have any cap (excitatory and inhibitory neurons that surround the Mauthner cells). The next groups of fish (purple, red, blue) all have Mauthner cells with caps that increase in complexity.

    b. Mauthner cells have not been observed in mammals, however, they still have a startle response. Propose an hypothesis that could help explain this observation.
       The startle response is conserved from fish to mammals because it is an important predator escape strategy. The startle response in mammals may be more complex and the function of Mauthner cells could be shared among more than one neuron. That could provide mammals with more sophisticated startle responses, as each neuron could be responsible for a specialized response.

Questions for Part 3:

1. What did scientists observe when they compared Hox genes between distantly related species? Choose all of the answers that apply.
    a. **Conservation of early stage enhancers.**
    b. **Conservation of late stage enhancers.**
    c. Protein sequence conservation.
    d. Intronic sequence conservation.
    e. Scientists did not observe any similarities among species.

For questions 2-4, determine if the statement is true or false.

2. The study of fossils and genes can help scientists to identify possible links between species.
   True.

3. The development of limbs in fish and humans is similar.
   True.

4. Hox genes are only activated during early stages of development.
   False.

5. Briefly explain how expression of Hox genes generates the appendages observed in limbs.
   Hox genes have two sets of enhancers; one that works during early development, and one that works later in development. The early-development enhancers are responsible for driving the development of the first two phases of the limb, while the late development enhancers are responsible for driving the development of digits and wrists.

6. Noggin is a protein involved in the differentiation of nerve cells. Cells in the region of the embryo that expresses noggin will start to differentiate into neural cells. This locks in the fate of the cells.
    a. When comparing development between species, scientists study the non-coding and coding regions of a gene. Why?
       During the development, when and where a gene is activated is critical for determining cell fate. Even if scientists find that a gene is present in different organisms, it needs to be turned on/off at the right time and place in the embryo. For this reason, scientists also compare the enhancers and regulators that turn genes on/off. Since these regulatory regions lie outside of the coding region of the gene, scientists need to study these regions too.

b. Some cells that undergo the same early developmental stages as neural cells, ultimately do not become neurons. For example, melanocytes (pigment producing cells) are derived from the neural lineage, but they differentiate into melanocytes later in development. Would you expect the same proteins that regulate the differentiation of neurons to be present in melanocytes? Briefly explain.
Melanocytes would have some neuron-specific proteins (those that regulate early development), and some proteins that are specific to melanocytes (those that dictate late development).

7. What experiments led scientists to propose the importance of Hox genes in the development of vertebrate limbs? Briefly explain.
Mutation of Hox genes led to the development of animals that lack bones (such as wrist bones or digits) in the limb. This observation lead to the conclusion that Hox genes specify the different structures of the appendages. For example, mutation of some Hox genes could lead to the development of a mouse without toes.