STUDENT GUIDE

Wiring your shark's brain

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Description

In this module, you will learn the shark cranial nerves by connecting nerves to a brain model of the spiny dogfish shark (*Squalus acanthias*), tracing their paths out of the braincase, and completing a schematic diagram.

Introduction

In sharks, the **chondrocranium** (meaning, "cartilaginous skull") is also known as the **braincase** because it *encases* the brain. The brain and spinal cord together form a **central nervous system** (abbreviated **CNS**), which receives, sends, and integrates information from all over the body. Think of the CNS as one continuous system with two names: within the braincase it's called the brain, whereas within the spine it's called the **spinal cord**.

When a structure receives neural supply from a nerve, it is said to be **innervated** by that nerve. For nerves to **innervate** structures in the body, they need to travel in and out of the CNS (braincase and spine). The nerves that enter and exit the CNS within the chondro*cranium* are called ***cranial* nerves** whereas those that enter and exit the CNS along the *spine* are called ***spinal* nerves**.

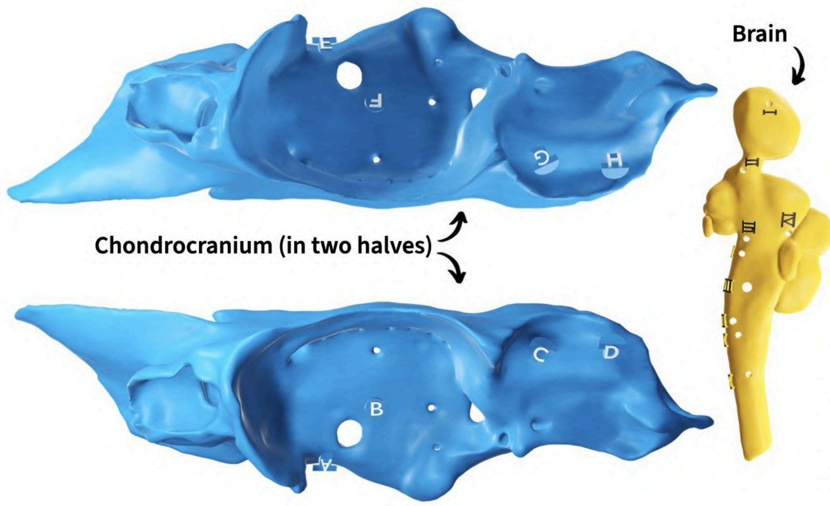
When you first learn the cranial nerves, they will just look like a long list of terms. It is always difficult to memorize a simple list of items (and you are very likely to forget them in the long term) because *your* brain doesn't have any additional context clues. If you learn the cranial nerves along with the context of their position, function, and development, you'll have an easier time remembering them.

In this module, you will learn this positional and functional context by "wiring up" cranial nerves (pipe cleaners) to the brain of your shark and tracing their paths out through the braincase toward their **innervation** targets. In the process, you'll also complete a corresponding "wiring diagram" to help you gain a conceptual understanding of the shark cranial nerves.

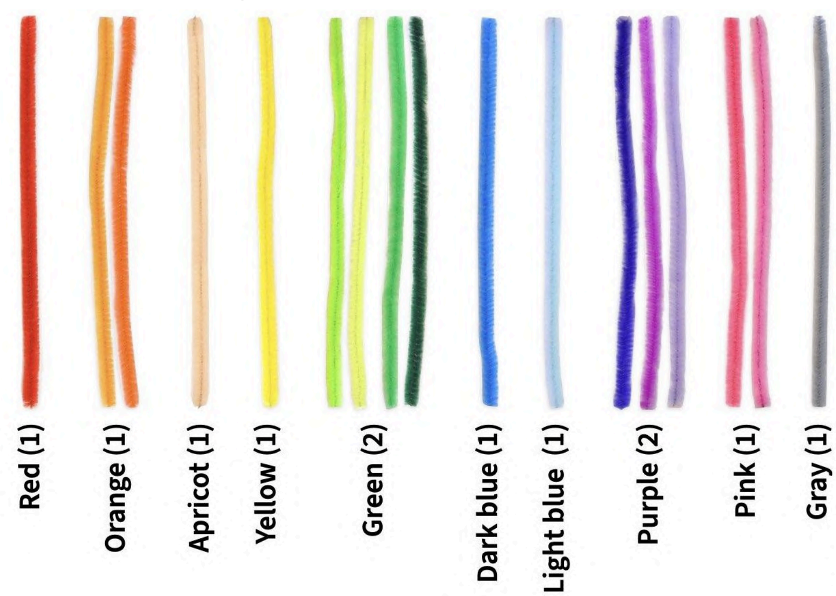
Materials needed

For this module, you'll need:

- The **Student Notebook** for this module (SA03).
- The **chondrocranium** and **brain** from your kit (see image below). The chondrocranium comes in two parts and these are the largest parts in the kit. If your kit is color coded, the chondrocranium pieces are blue and the brain is yellow.

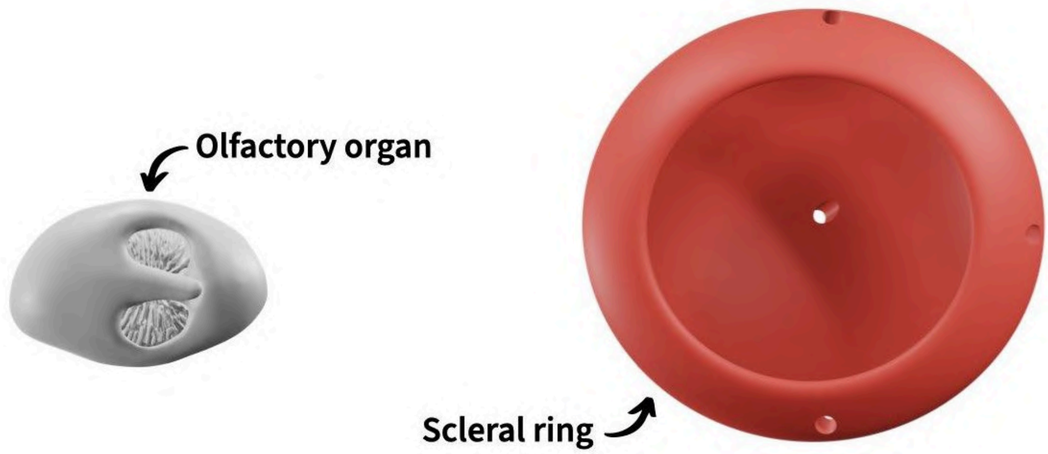


- The **pipe cleaners** from your kit. You should have 15 total but you'll only need 12 for this module (all *except* white, brown & black). Use the image below to find the 12 you need. For most colors, you'll have one pipe cleaner, indicated by "(1)" in the image. Where there are two pipe cleaners with a "(1)", you'll have one pipe cleaner matching one of the two colors. For green and purple, you'll have two pipe cleaners each.



Materials needed (continued)

- The **olfactory organ** and **scleral ring** from your kit.



COLOR NOTE: Color scheme optional

The use of particular colors for particular nerves or even different colors for different nerves is not essential for this module. If you're unable to distinguish among colors or want to use a different color scheme, feel free to disregard any color-related instructions.

Section 1. What are your shark's cranial nerves and where do they go?

The vertebrate cranial nerves are referred to by either their name, their number (as a roman numeral following "CN"), or both. For example, the first cranial nerve may be referred to in any of the following ways, where "n." is the abbreviation for nerve:

"CN I Olfactory n." or "CN I" or "Olfactory n." or "Olfactory n. (CN I)"

In this guide, the roman numeral will generally be included with the name to help you learn both the name and number for each nerve.

You'll connect your cranial nerves following the sequence of these roman numerals. As you'll see, this sequence goes approximately from the **rostral** (or **anterior**) end of the braincase (the front end, closest to the snout) to the **caudal** (or **posterior**) end of the braincase (toward the tail). This is, in part, because fish were used as a model when numbering the vertebrate cranial nerves. This fishy numbering scheme is used for *all* vertebrates, including humans.

Lateral line nerves

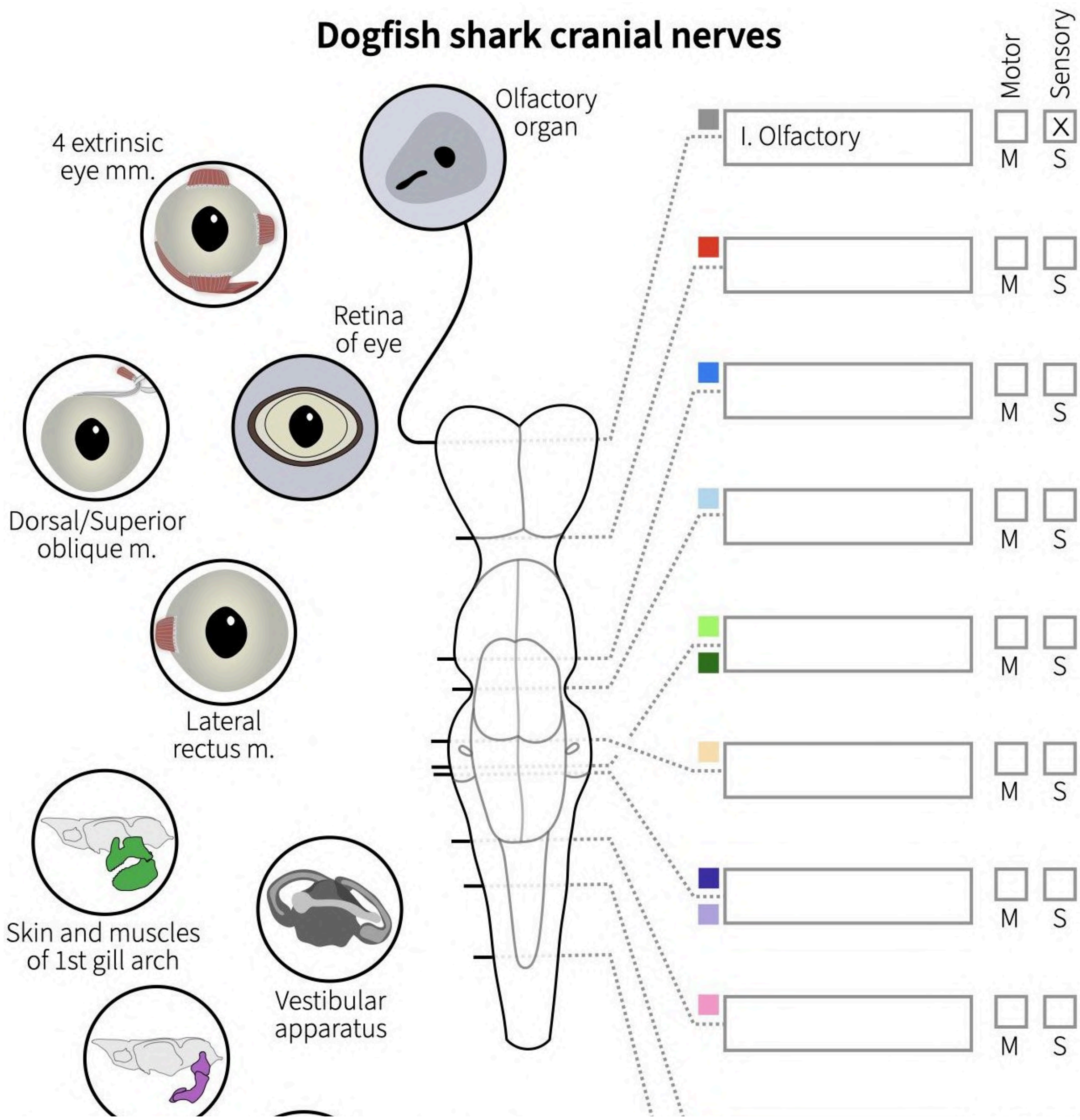
You'll often see a total of 10 cranial nerves listed for sharks, all having the same names as the first 10 cranial nerves in humans. It was previously thought that the **lateral lines** of fishes (sensory organs that can sense mechanical and, sometimes, electrical stimuli) were innervated by some of these 10 cranial nerves. However, it has recently been found that the lateral lines are innervated by a separate set of cranial nerves that connect to the brain in several different places and constitute an 11th cranial nerve. Thus, the lateral lines don't have an assigned roman numeral, like the other nerves. Additionally, since these nerves connect to the brain in many places, you won't connect any pipe cleaners representing the lateral lines in this activity. However, they are cranial nerves just as much as any other cranial nerve.

Olfactory nerve (CN I)

The first cranial nerve is the **olfactory n. (CN I)**. As the name implies (**olfaction** is the sense of smell), this nerve carries sensory information from the **olfactory organ** (or "nose"). Write in the name for this nerve on the schematic on page 1 of your **Notebook** and draw in the path of the nerve from the brain out to its target structure; also, indicate whether it carries sensory information, motor information, or both. Once you've finished, check your work against the solution on the following page.

ASSESS: CN I added

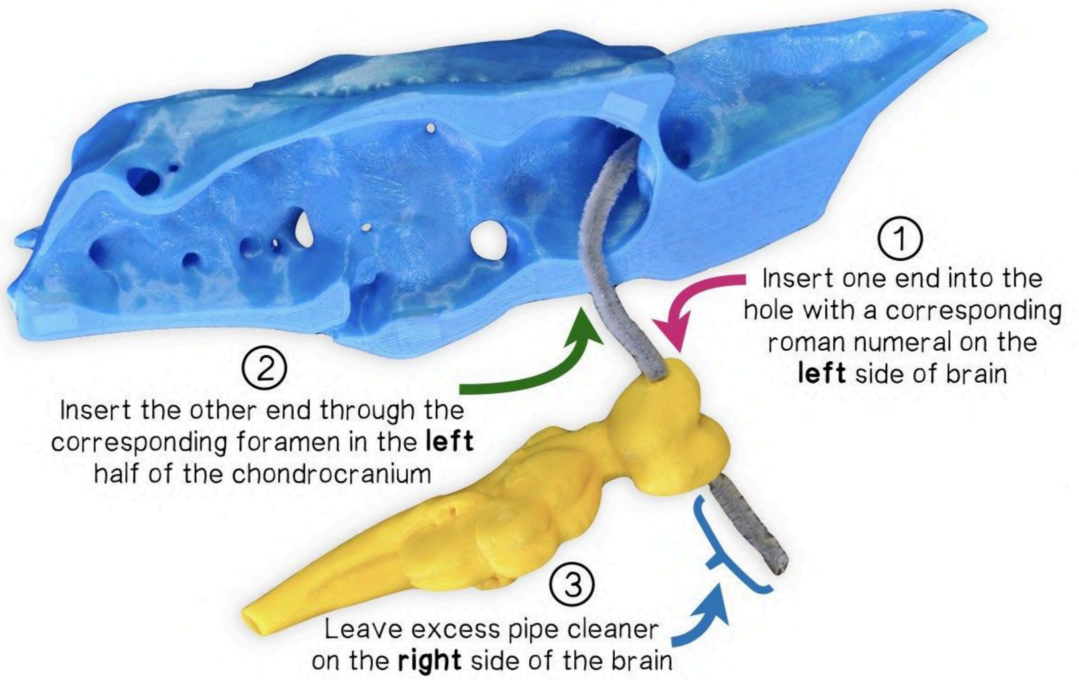
After adding the first cranial nerve, the schematic on page 1 of your **Notebook** should look like this, including a line drawn from the brain to nerve's target structure:



BUILD NOTE: Adding pipe cleaners

Use the following general steps to add each pipe cleaner (cranial nerve) to your brain:

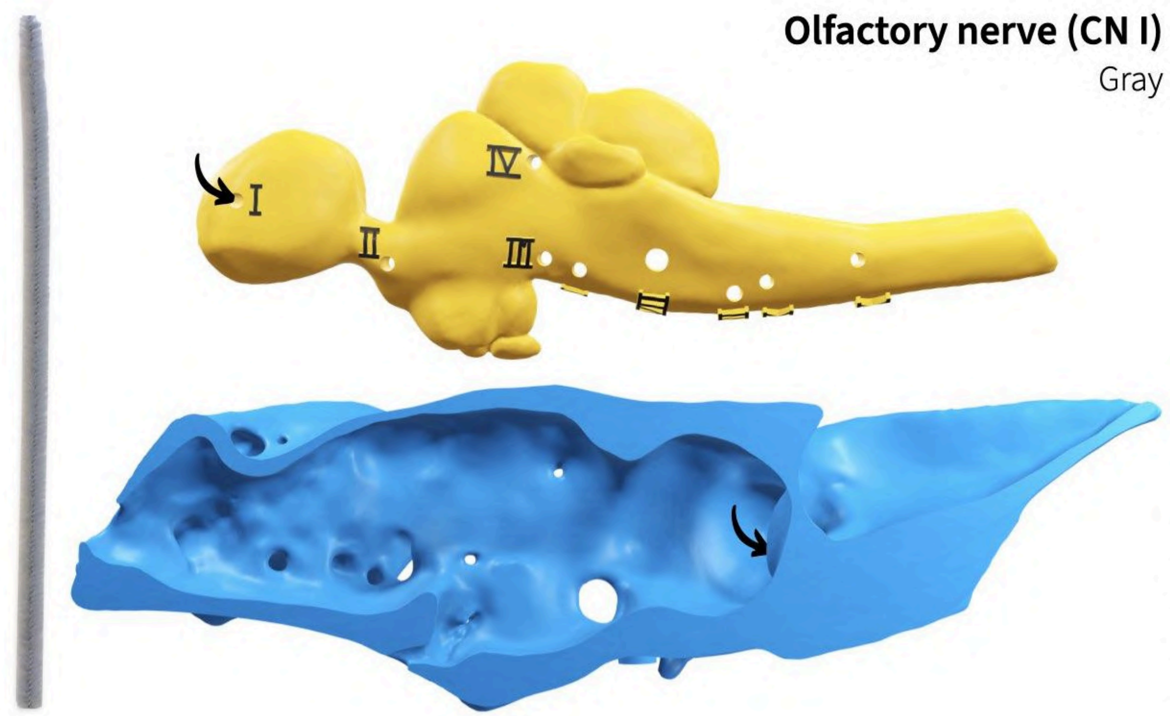
1. Insert each cranial nerve into the hole on the *left* side of the brain with the corresponding roman numeral. If your pipe cleaners are bent, straighten them out a bit; this will make them easier to insert through the holes.
2. Guide the other end of the cranial nerve out through its corresponding foramen in the *left* half of the chondrocranium.
3. Pull the cranial nerve all the way through the hole until there is some excess on the *right* side of the brain. Having this extra bit on the right side will keep the nerve from pulling out of the brain as you insert it through the chondrocranium.



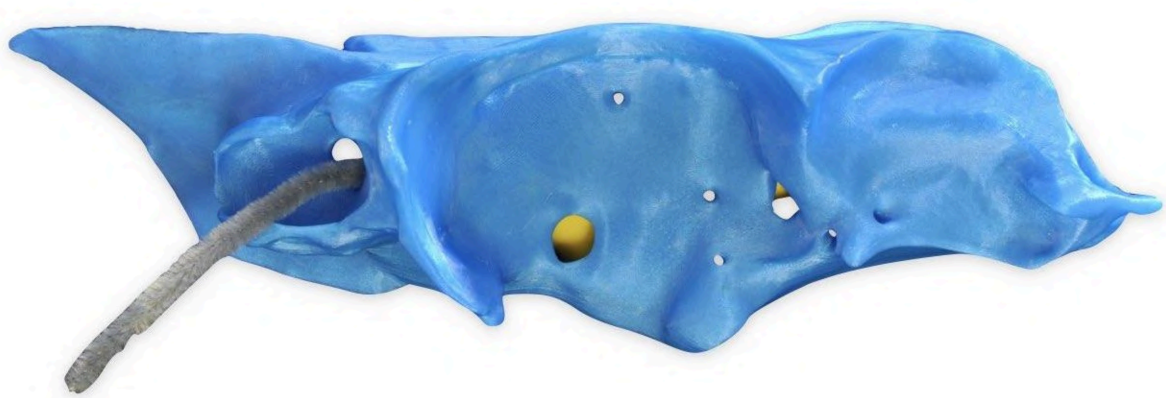
CAUTION: Pipe cleaner ends are sharp!

The pipe cleaners are made from thin wires so the cut ends can be **SHARP**. Be careful when pushing or pulling them through holes so that you don't cut yourself.

Add a pipe cleaner representing olfactory n. (CN I) to your brain by taking the gray pipe cleaner and inserting it through the rostral-most hole in the brain labeled with the roman numeral "I."



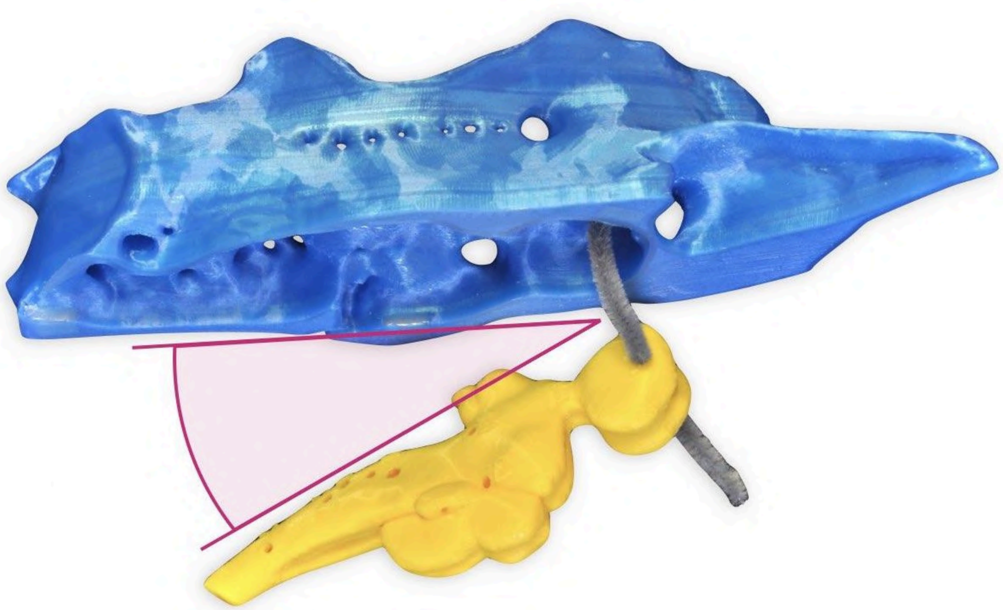
Guide the free end of the olfactory n. (CN I) out through its **foramen** (hole) in the left half of the chondrocranium: the rostral-most foramen exiting the **endocranial cavity** (the space inside the chondrocranium that houses the brain).



The olfactory n. passes through the rostral-most foramen to reach the **nasal capsule**, the cartilage encasing the olfactory organ.

BUILD NOTE: Keep space to add more

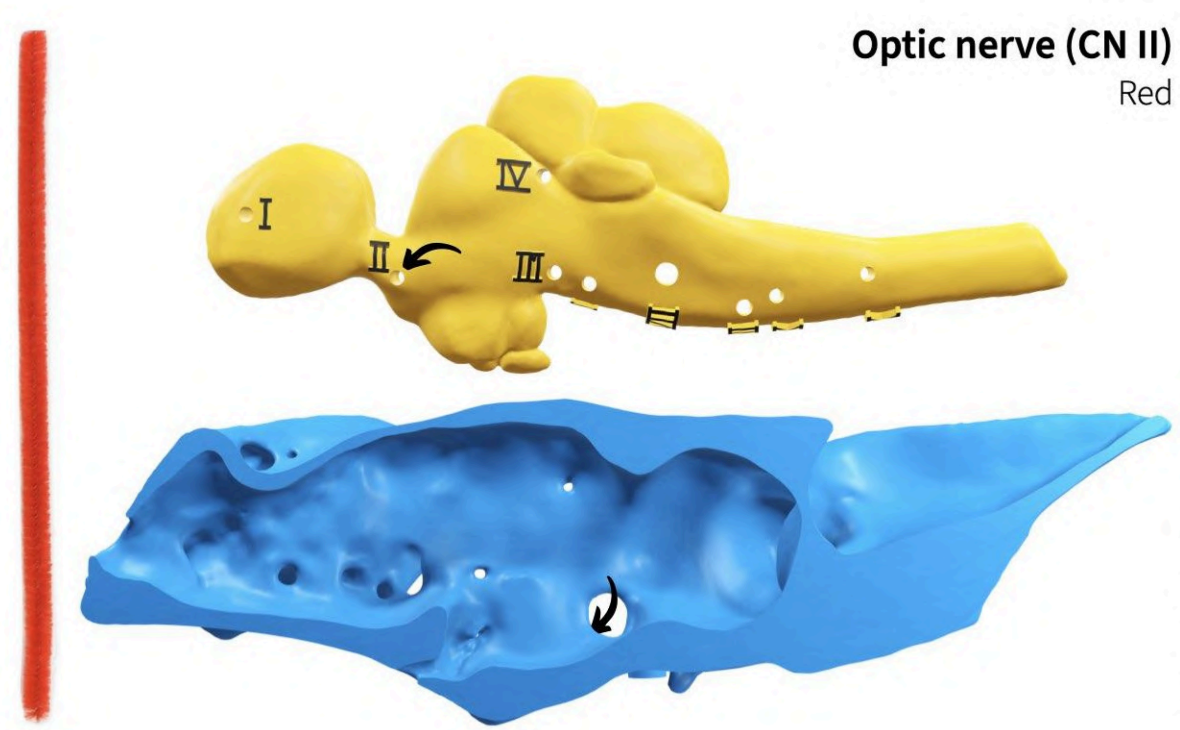
As you add more cranial nerves, it's easier to keep the chondrocranium and brain side by side with a slight angle between them, as shown in the image below. This will give you space to add additional nerves while keeping the previous nerves in place.



Optic nerve (CN II)

The second cranial nerve is the **optic n. (CN II)**. This nerve carries visual sensory information from the **retina** of the eye. On page 1 of your **Notebook**, write in the name of this nerve, draw its path from the brain out to its target structure, and indicate whether it is sensory, motor, or both.

Connect a red pipe cleaner, representing the optic n. (CN II), to the hole in the brain marked "II" and guide it out through its corresponding foramen in the chondrocranium. Use the following image to help you.

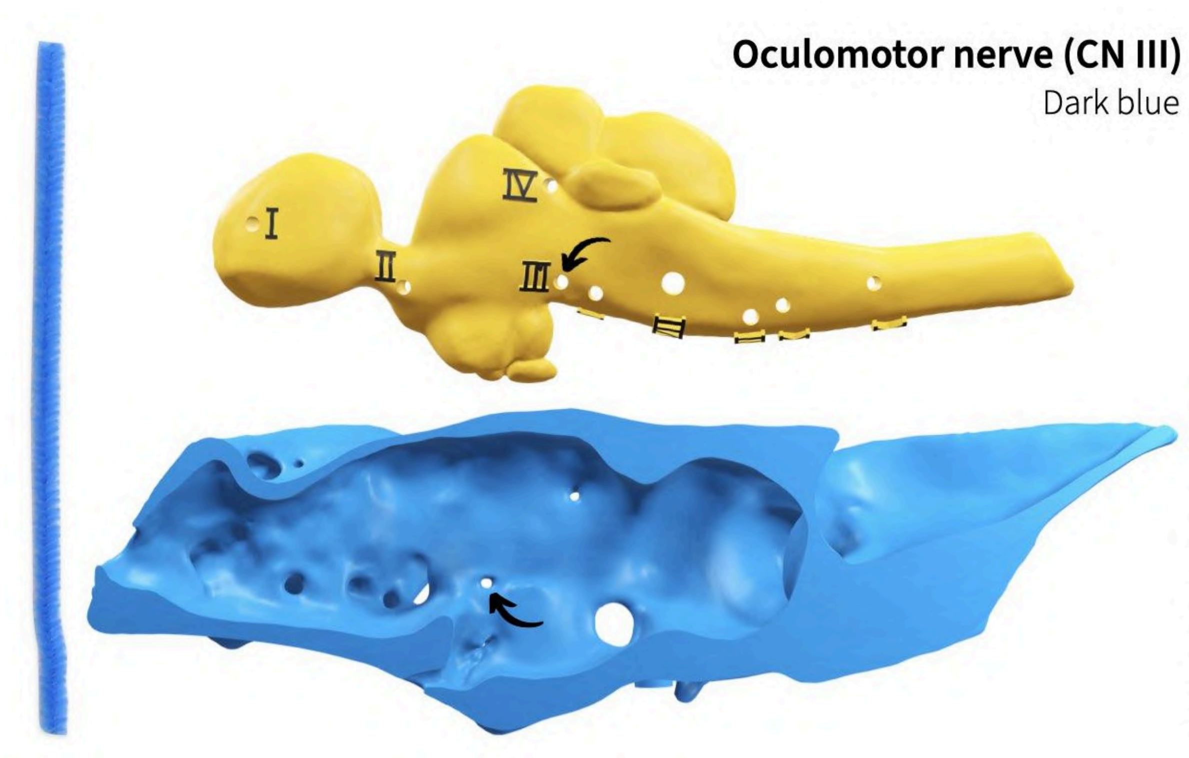


Oculomotor nerve (CN III)

Next is the third cranial nerve, the **oculomotor n. (CN III)**. As the name implies ("oculo-" means related to the eye or vision), this nerve also goes to the eye. However, it is a **motor nerve**, which means that rather than *receiving* sensory information, it *sends* information that causes muscles to contract.

Vertebrates have six muscles that attach to the outside of the eyeball to rotate it within the orbit; these six muscles are referred to as the **extrinsic eye muscles** (the muscles inside the eye, controlling the lens and pupil, are the ***intrinsic* eye muscles**). The oculomotor n. (CN III) sends motor signals to four of these six extrinsic eye muscles: **dorsal rectus**, **ventral rectus**, **medial rectus**, and **ventral oblique** (also known as **inferior oblique**). On page 1 of your **Notebook**, write in the name of the oculomotor n. (CN III), draw its path from the brain out to its target structure, and indicate whether it is sensory, motor, or both.

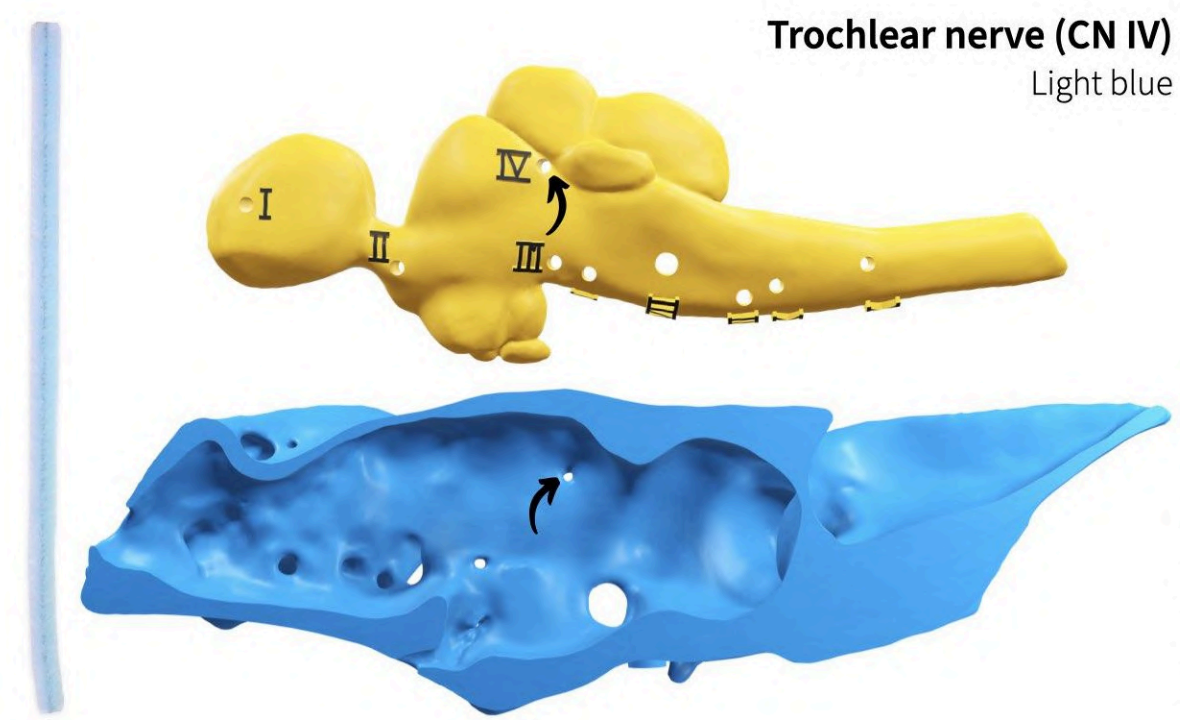
Connect a dark blue pipe cleaner, representing the oculomotor n. (CN III), to the hole in the brain marked "III" and guide it out through its corresponding foramen in the chondrocranium. Use the following image to help you.



Trochlear nerve (CN IV)

The fourth cranial nerve innervates another of the six extrinsic eye muscles: the **dorsal oblique** (also known as the **superior oblique**). On page 1 of your **Notebook**, write in the name of the trochlear n. (CN IV), draw its path from the brain out to its target structure, and indicate whether it is sensory, motor, or both.

Connect a light blue pipe cleaner, representing the trochlear n. (CN IV), to the hole in the brain marked "IV" and guide it out through its corresponding foramen in the chondrocranium. Use the following image to help you.

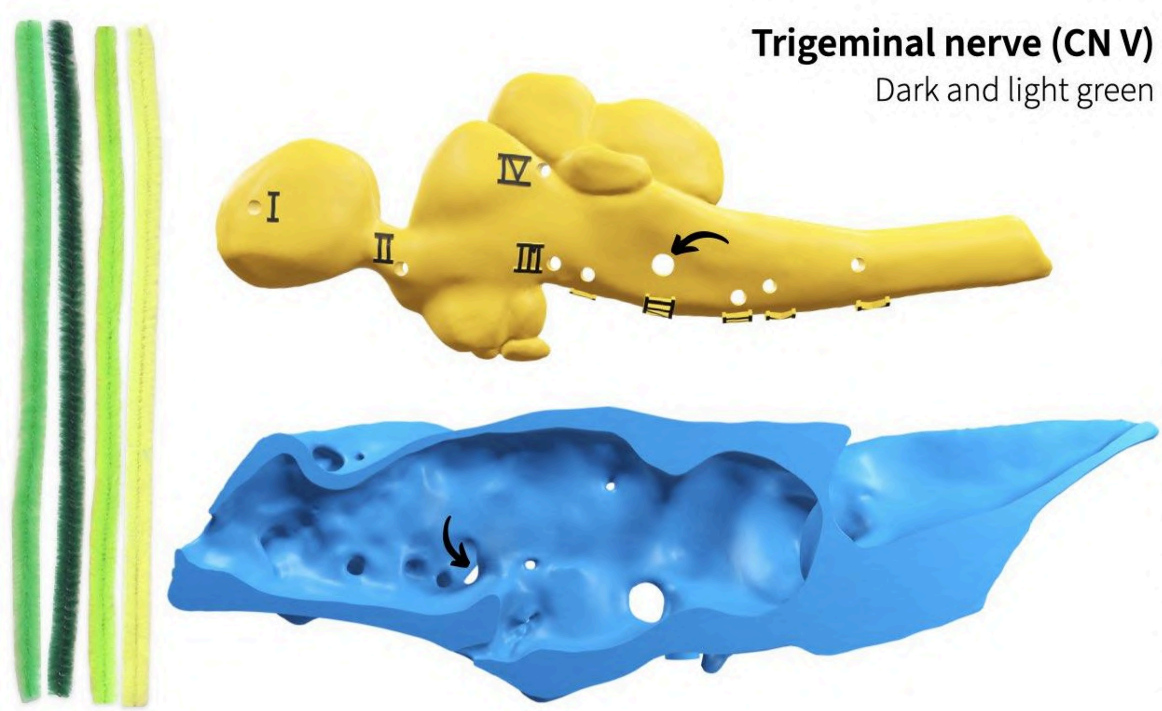


Trigeminal nerve (CN V)

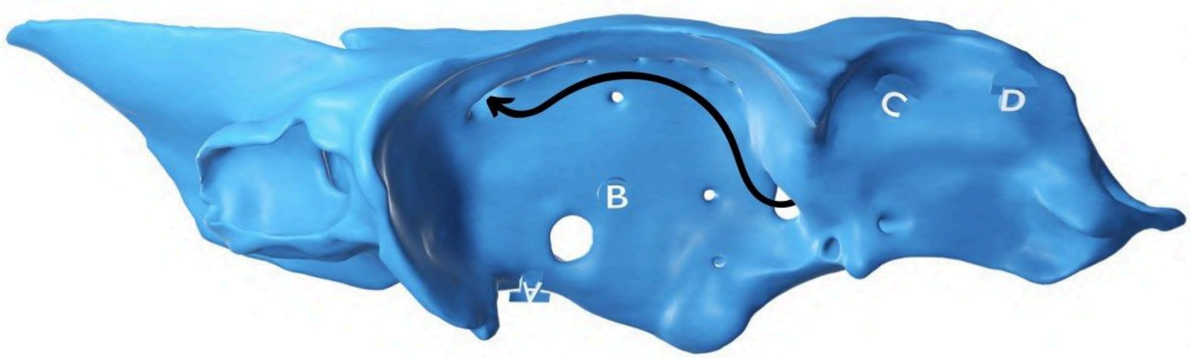
Until now, all of the cranial nerves have either been sensory (CN I and II) or motor (CN III and IV). The fifth cranial nerve, the **trigeminal n. (CN V)**, has both sensory and motor components. The sensory component receives tactile information from the skin covering the rostral-most portion of the head and around the mouth, whereas the motor component innervates the rostral-most jaw muscles.

The trigeminal n. (CN V) receives its name from the fact that it immediately splits into three branches ('trigeminus', three born at the same time). The first branch goes to the skin around the eyes and snout, the second branch to the skin and muscles of the upper jaw (**palatoquadrate**), and the third branch to the skin and muscles of the **lower jaw** (or **mandible**). In this way, all structures derived from the first of the seven **gill arches** receive innervation from the trigeminal n. (CN V). On page 1 of your **Notebook**, write in the name of the trigeminal n. (CN V), draw its path from the brain out to its target structure, and indicate whether it is sensory, motor, or both.

Connect *two* green pipe cleaners, representing two of the three trigeminal n. (CN V) branches, to the hole in the brain marked "V/VII" and guide them out through the foramen in the chondrocranium indicated in the image below. Use the following image to help you.

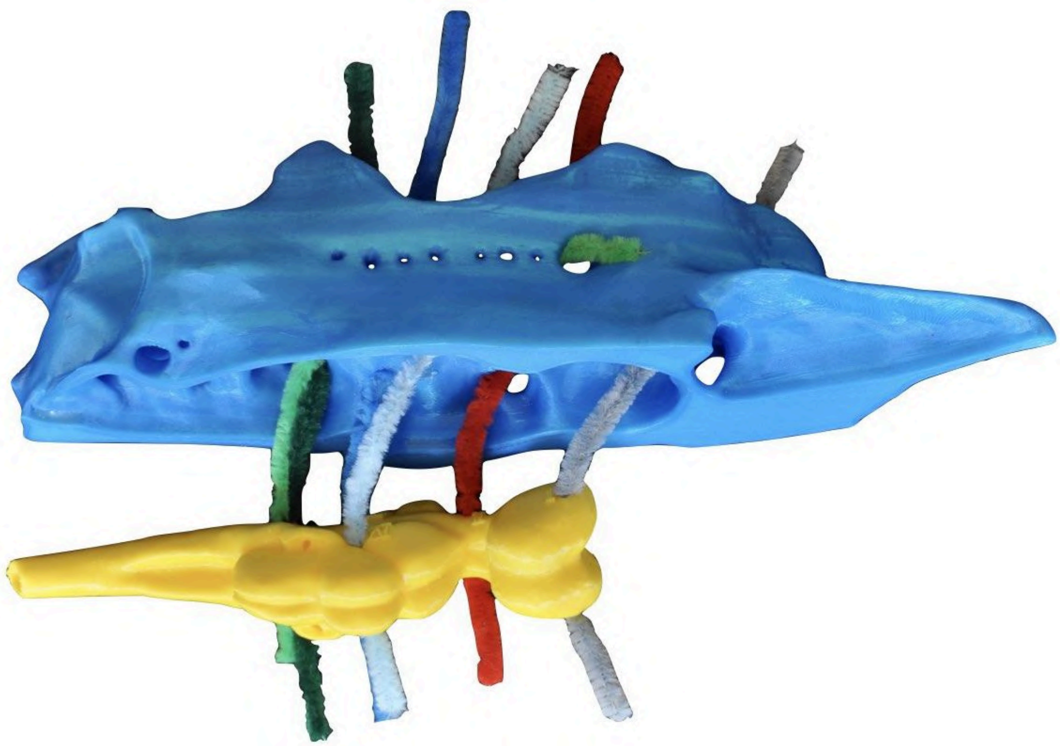


Once you've pulled your two trigeminal nerves outside of the endocranial cavity, guide one of the branches through the rostral-most foramen in the roof of the orbit. This is the branch that innervates sensory structures on the rostrum of the skull.



ASSESS: Half of cranial nerves added

You've now connected half of your shark's 10 cranial nerves! Nice job! Before proceeding, take a moment to compare your chondrocranium and brain against the following image to make sure you have everything inserted correctly.

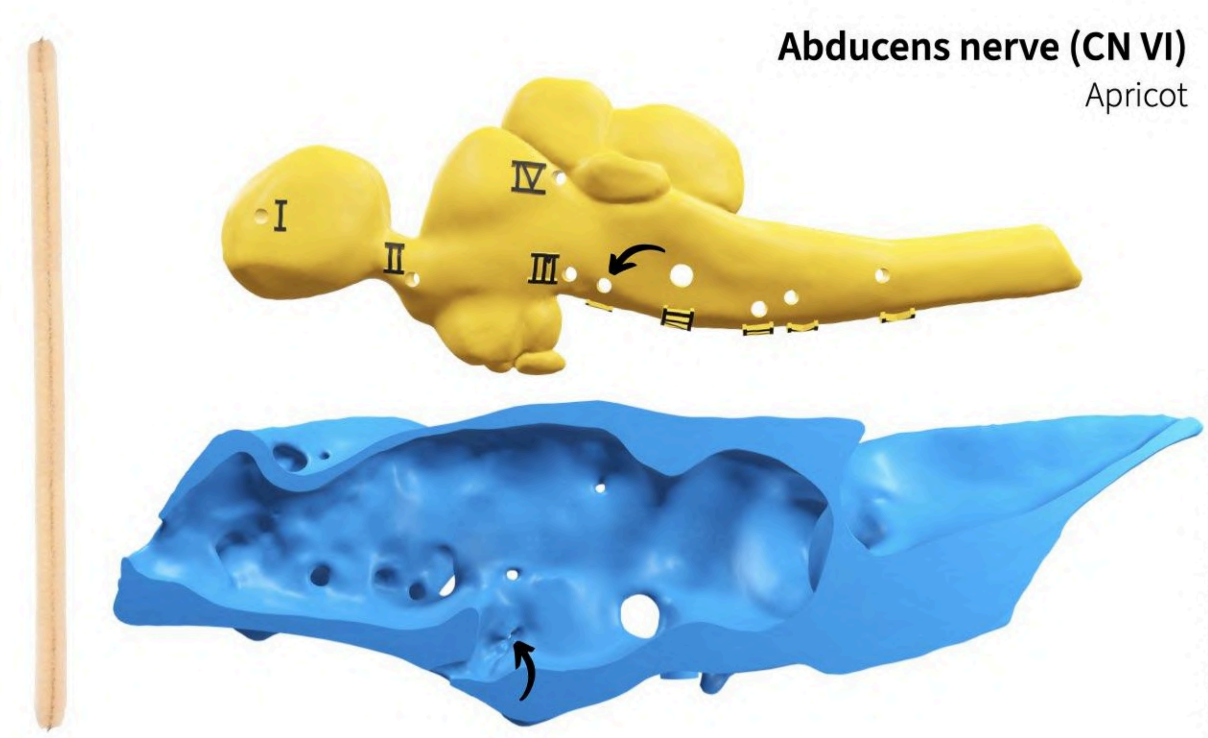


Abducens nerve (CN VI)

So far we've accounted for the innervation of five of the six extrinsic eye muscles. The sixth cranial nerve, **abducens n. (CN VI)**, provides motor innervation to the remaining extrinsic eye muscle: the **lateral rectus**. The name "abducens" comes from the fact that the lateral rectus **abducts** the eye (pulls it laterally, away from the midline).

On page 1 of your **Notebook**, write in the name of the abducens n. (CN VI), draw its path from the brain out to its target structure, and indicate whether it is sensory, motor, or both.

Connect the apricot pipe cleaner, representing the abducens n. (CN VI), to the hole in the brain marked "VI" and guide it out through its corresponding foramen in the chondrocranium. Use the following image to help you.

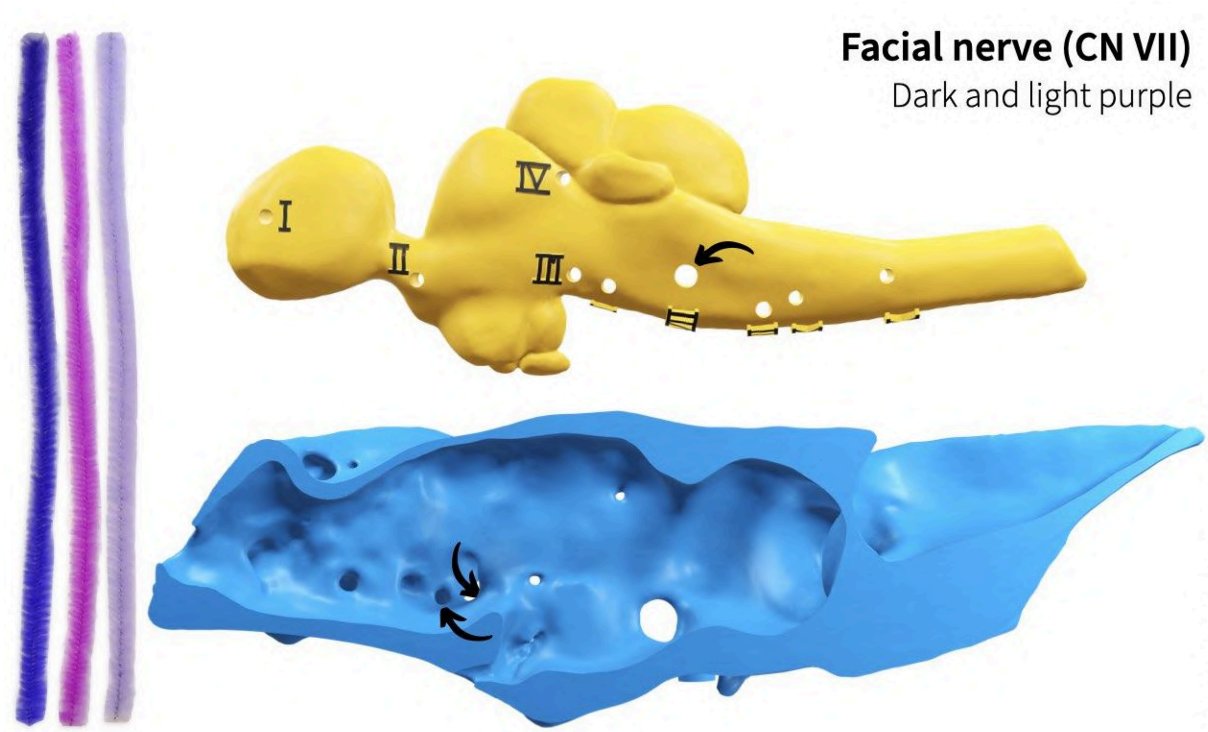


Facial nerve (CN VII)

If the fifth cranial nerve had a buddy, it would be the seventh cranial nerve, the **facial n. (CN VII)**. The facial n. (CN VII), provides sensory and motor innervation to the epithelium and muscles associated with the second of the seven gill arches. This includes sensory information from taste buds inside the mouth. On page 1 of your **Notebook**, write in the name of the facial n. (CN VII), draw its path from the brain out to its target structure, and indicate whether it is sensory, motor, or both.

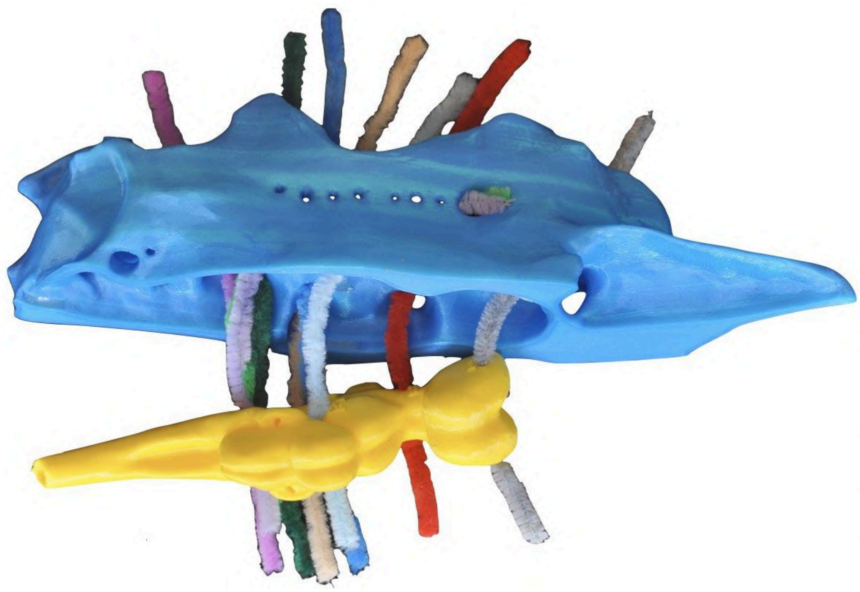
Connect *two* purple pipe cleaners, representing two branches of the facial n. (CN VII), to the brain. The close association between the trigeminal and facial nerves extends to where they leave the brain: they emerge as a single root. Thus, you'll insert the facial n. into the same hole in the brain as the trigeminal n., marked "V/VII." Guide the two pipe cleaners out through each of two foramina in the chondrocranium indicated in the image below. One of these foramina leads more rostrally while the other leads more caudally.

One of these branches travels with the trigeminal branch that exits through the roof of the orbit to also innervate sensory structures on the rostrum of the skull. Guide the more rostral of the two facial n. (CN VII) branches to follow the path of this trigeminal branch.

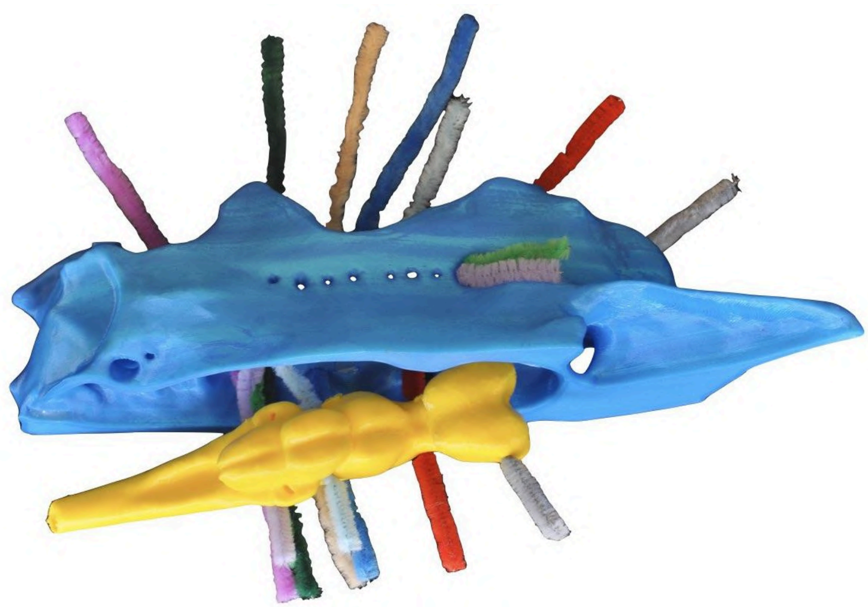


BUILD NOTE: Moving the brain in

Now that you've connected 7 of the 10 cranial nerves, it's a good time to start moving the brain into the endocranial cavity (you'll be able to pull it all the way in once you've attached all 10 cranial nerves).

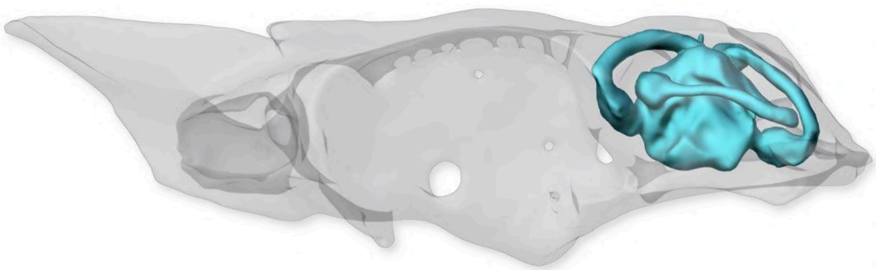


Start by pulling some of the cranial nerves through to the left side of the chondrocranium. For now, still keep the excess pipe cleaner length on the right side of the brain. Your chondrocranium and brain should look like the image below.



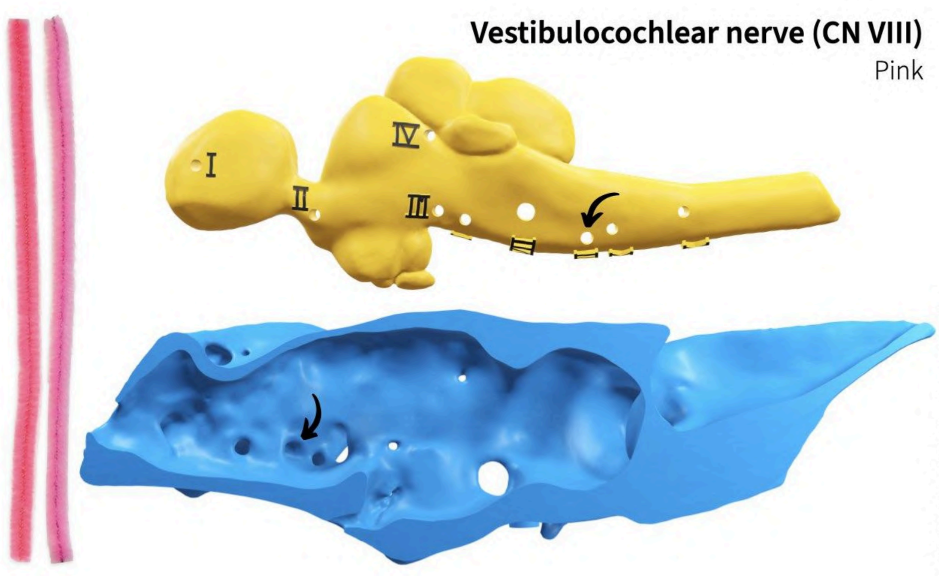
Vestibulocochlear nerve (CN VIII)

All of the cranial nerves you've seen so far leave the brain and exit the chondrocranium to reach their target. The eighth cranial nerve, the **vestibulocochlear n. (CN VIII)**, is different. It carries sensory information from a structure entirely contained within the chondrocranium, the **vestibular apparatus**, shown in the image below. The vestibular apparatus allows vertebrates to perceive their orientation and acceleration and in some sharks, including dogfish, it senses sounds transmitted through the openings of the **endolymphatic duct** (Chapuis & Collin 2022).



Although this nerve has "cochlear" in its name, sharks do not have a **cochlea**. The cochlea, also innervated by the vestibulocochlear n. (CN VIII) nerve, evolved in mammals as an outgrowth of the vestibular apparatus. On page 1 of your **Notebook**, write in the name of the vestibulocochlear n. (CN VIII) nerve, draw its path from the brain out to its target structure, and indicate whether it is sensory, motor, or both.

Connect a pink pipe cleaner, representing the vestibulocochlear n. (CN VIII), to the hole in the brain marked "VIII" and guide it into its corresponding canal in the chondrocranium.

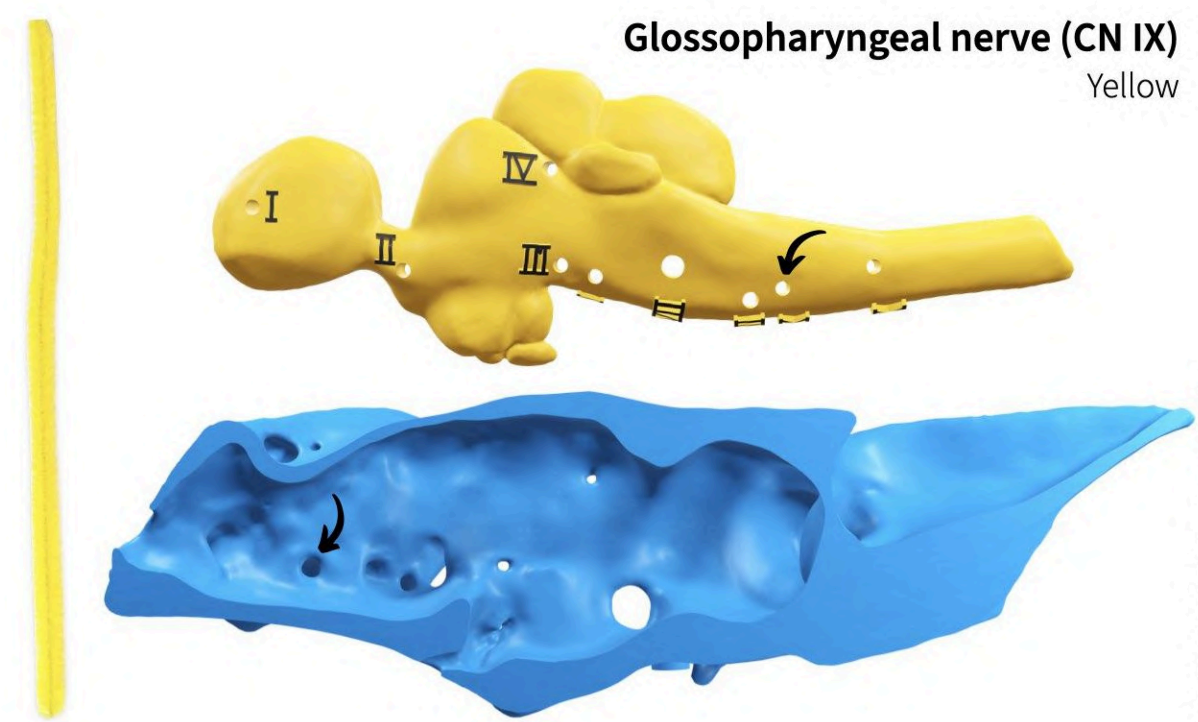


Glossopharyngeal nerve (CN IX)

You've already added cranial nerves that innervate structures derived from the first two gill arches: the trigeminal and facial nerves (V and VII, respectively). The ninth cranial nerve, the **glossopharyngeal n. (CN IX)**, innervates structures derived from the third gill arch. The third gill arch corresponds approximately to the start of the **pharynx**, the part of the digestive tract immediately after the mouth (i.e., what you might commonly call the "throat"). This innervation includes motor control of the muscles that attach to the third gill arch, sensory innervation to the skin around the third arch, and the internal epithelium of the pharynx.

The first part of the name "glosso-" ("tongue") is similar to "-cochlear" in the name of the previous cranial nerve. Although sharks don't have a tongue, the glossopharyngeal n. (CN IX) is one of the nerves that innervates the tongue in other vertebrates. On page 1 of your **Notebook**, write in the name of the glossopharyngeal n. (CN IX), draw its path from the brain out to its target structure, and indicate whether it is sensory, motor, or both.

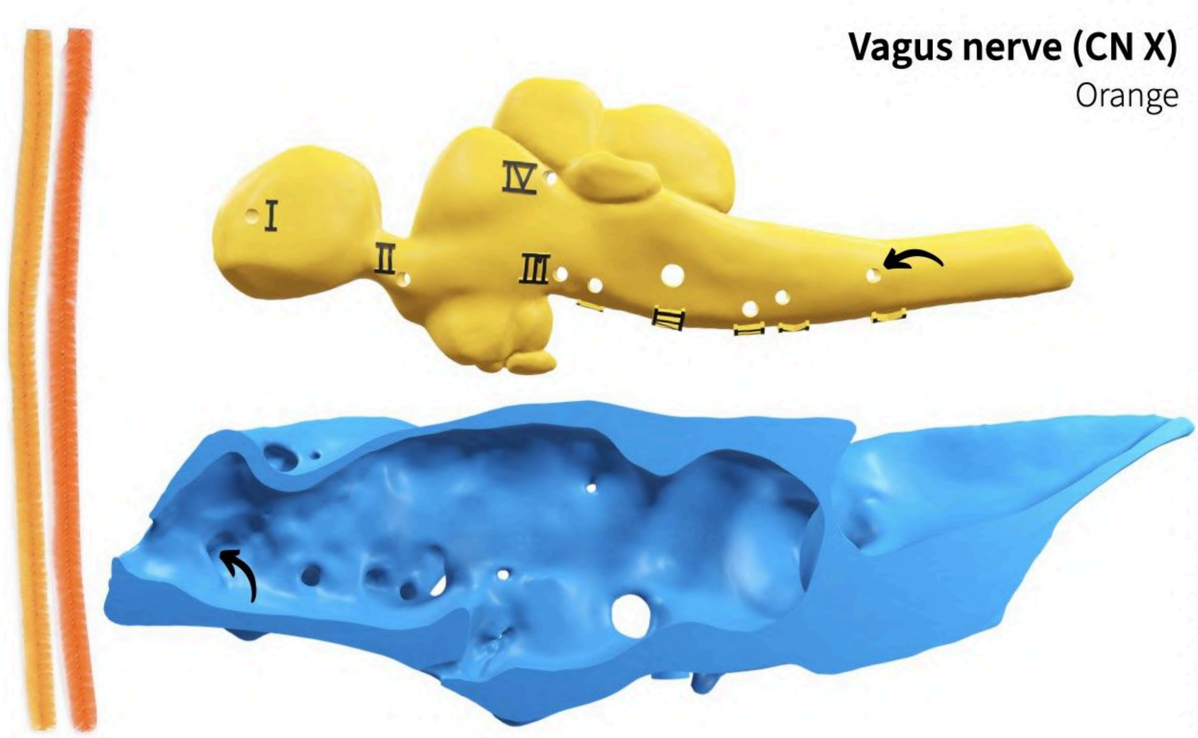
Connect a yellow pipe cleaner, for the glossopharyngeal n. (CN IX), to the hole in the brain marked "IX" and guide it through its corresponding canal in the chondrocranium. You might find it easier to insert through the chondrocranium first. Use the following image to help you.



Vagus nerve (CN X)

The tenth cranial nerve is the **vagus n. (CN X)**. The name "vagus" comes from the Latin word for "wandering" and if you were to follow this nerve's path through the body, you would indeed find it wanders: from the brain down to the esophagus, heart, stomach, and all the way to the intestines. The vagus n. (CN X) provides sensory and motor innervation to structures derived from the remaining fourth through seventh gill arches and to most of the gut. On page 1 of your **Notebook**, write in the name of the vagus n. (CN X), draw its path from the brain out to its target structure, and indicate whether it is sensory, motor, or both.

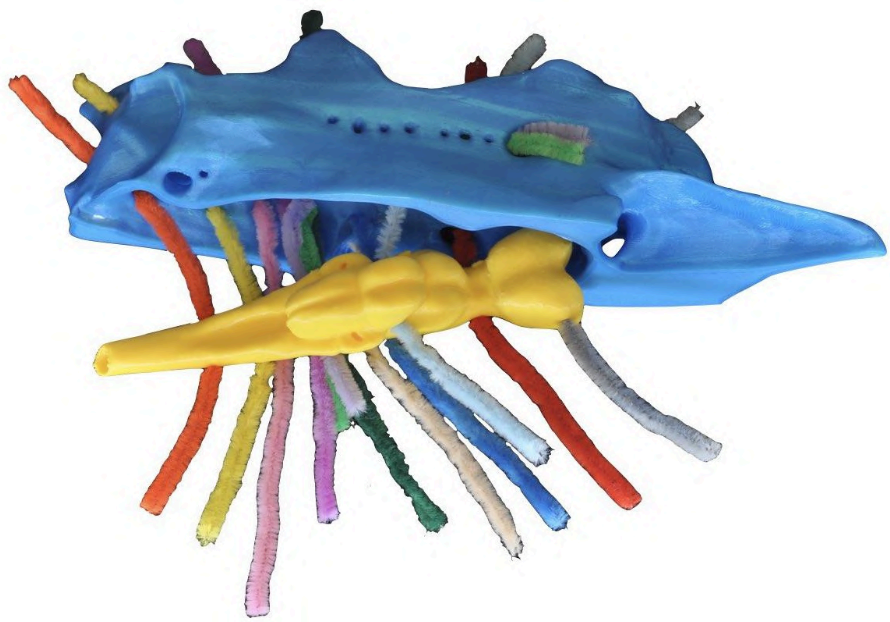
Connect an orange pipe cleaner, representing the vagus n. (CN X), to the hole in the brain marked "X" and guide it through its corresponding canal in the chondrocranium. You might find it easier to insert through the chondrocranium first. Use the following image to help you.



All the cranial nerves added

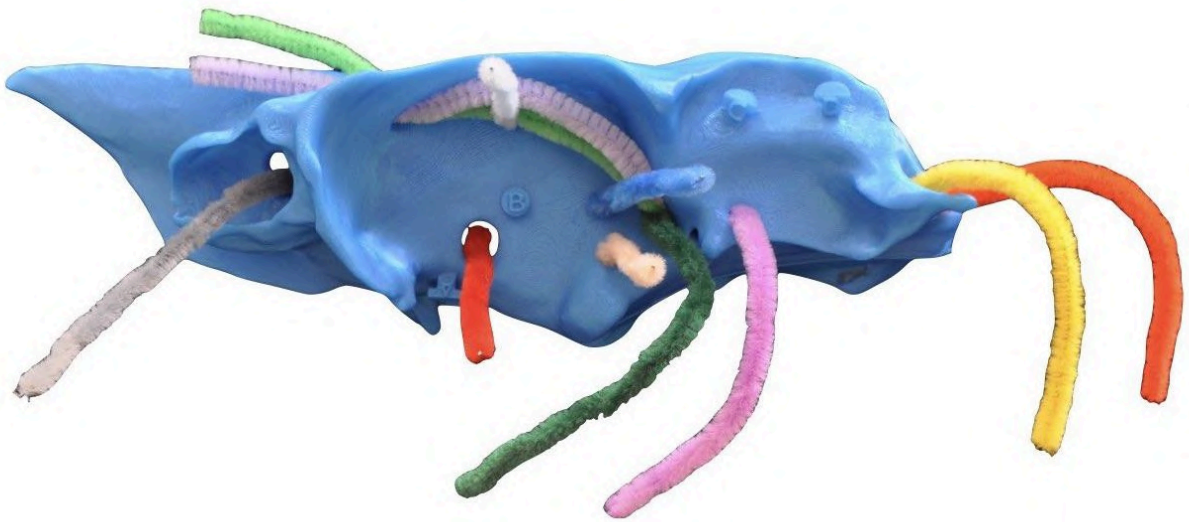
ASSESS: All cranial nerves added

Once you've added all of the cranial nerves, your shark's chondrocranium and brain should look something like this:



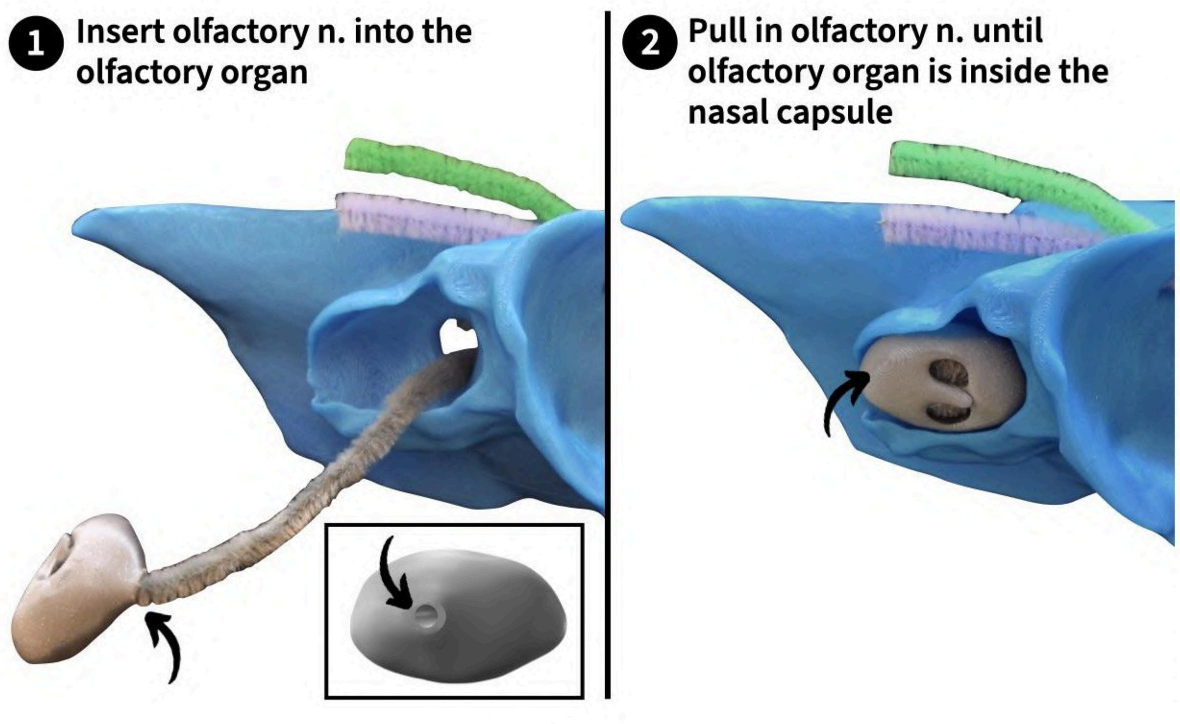
Push the brain completely into the endocranial cavity. As you do so, pull the cranial nerves I, V, VII, IX, and X from where they emerge from the chondrocranium until they're near flush with the right side of the brain. As you do, **be careful of the sharp ends of the pipe cleaners**! You don't need to pull through cranial nerves II, III, IV, VI and VIII; just fold them over the brain. When you're finished, your brain should look similar to the image below.

You should now be able to close up the chondrocranium with all of the emerging cranial nerves visible on the left side.



Adding the olfactory organ and scleral ring

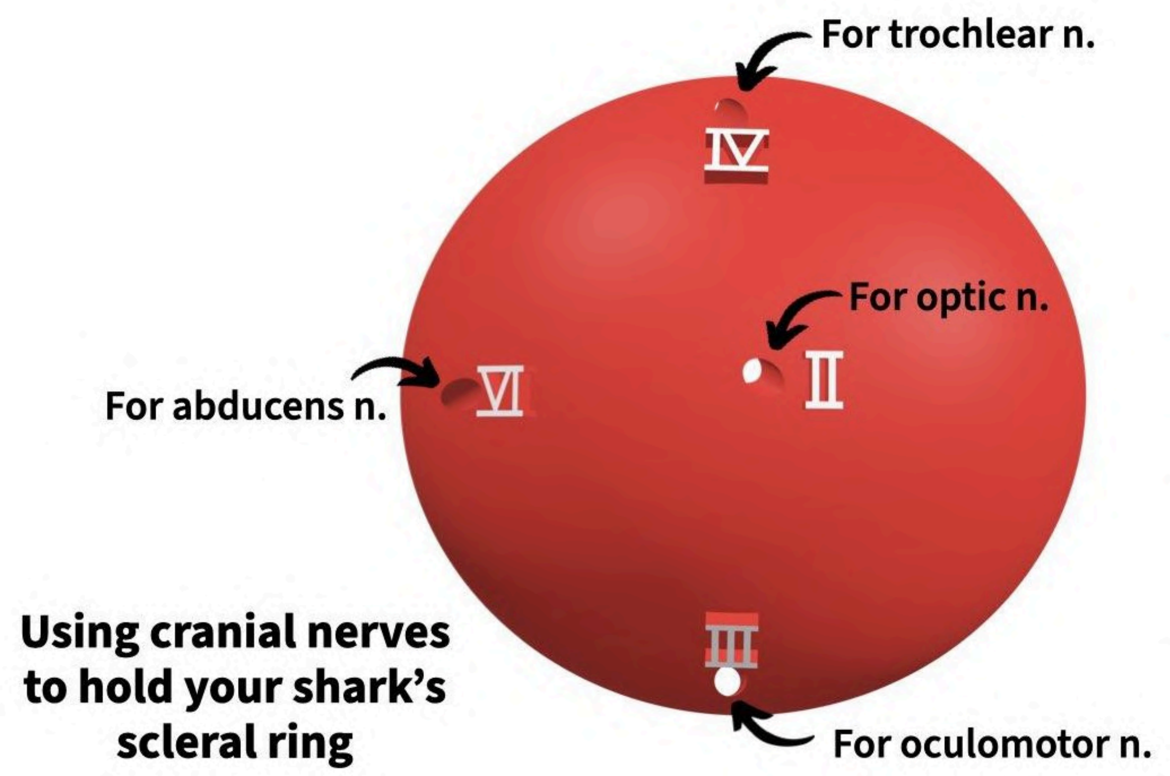
If you'd like, you can connect some of your cranial nerves to their target structures. In your kit find your shark's olfactory organ. This is the organ that your shark uses to smell. Connect the olfactory nerve to the hole in the back of the olfactory organ and then pull the olfactory nerve through the brain toward the right until the organ is fully housed within the chondrocranium.


1 Insert olfactory n. into the olfactory organ
2 Pull in olfactory n. until olfactory organ is inside the nasal capsule

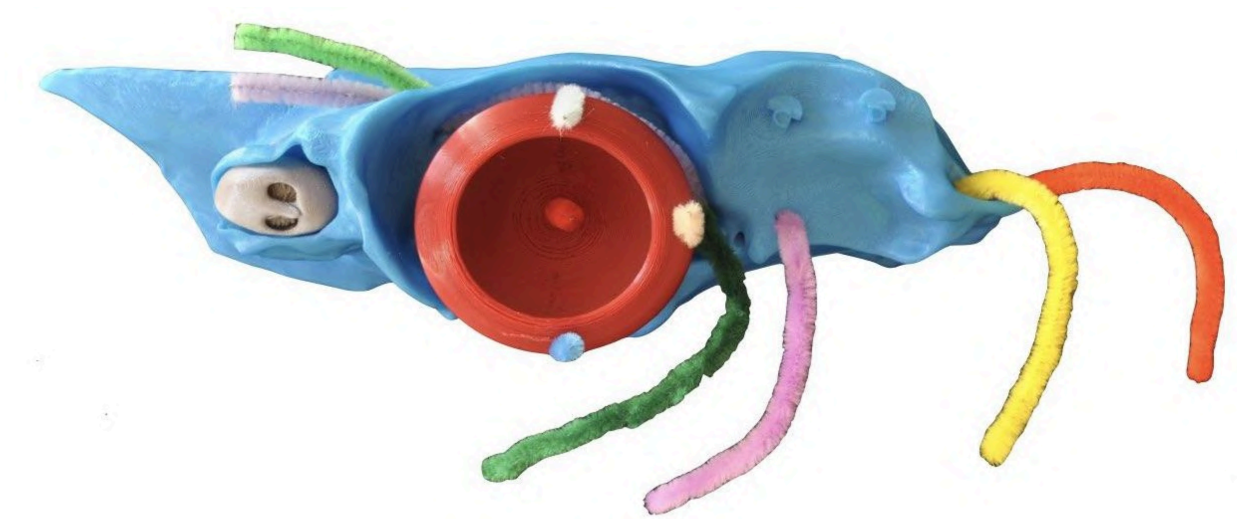
Your kit doesn't include an eyeball but it does include a **scleral ring**, mineralized tissue (in this case cartilage) within the eyes of most vertebrates, the function of which isn't entirely clear (Franz-Odendaal 2020). This scleral ring represents the general shape and size of the eyeball.

The eye cranial nerves *don't connect to the scleral ring* -the oculomotor, trochlear, and abducens nerves connect to the extrinsic muscles of the eye and the optic nerve connects to the retina of the eye. However, you'll attach them here just to hold the ring in place and to represent the general locations of these nerves relative to the eye. Also, the scleral ring in your kit is *much thicker* than the actual scleral ring in dogfish sharks (so that it could be 3D printed).

Find the scleral ring in your kit (the red cup-shaped piece). Insert the four cranial nerves that innervate structures of the eye through the backside of the ring, using the raised labels and image below to help you.



Slide the scleral ring toward the chondrocranium, continuing to pull each of the four cranial nerves through the holes until the scleral ring is entirely within the left orbit.



Summing up the form and function of the chondrocranium

Take a moment to observe your chondrocranium with all of the cranial nerves. Based on what you observe, how would you explain the structure and function of the chondrocranium in a *single* sentence? Write your response in your **Notebook**.

Nice work! You've added all of the cranial nerves to your shark and some of the target structures! If you're building your shark's jaws and branchial arches after this, you can keep all of the cranial nerves in place and lead CNs V, VII, IX, and X to their targets too.

References cited

- Chapuis, Lucille, and Shaun P. Collin. "The auditory system of cartilaginous fishes." *Reviews in Fish Biology and Fisheries* 32.2 (2022): 521-554. DOI: 10.1007/s11160-022-09698-8.
- Franz-Odendaal, Tamara Anne. "Skeletons of the eye: An evolutionary and developmental perspective." *The Anatomical Record* 303.1 (2020): 100-109. DOI: 10.1002/ar.24043.