Magnetic Fields

8.5

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Anchoring Phenomenon

Numerous reports suggest an increase in white shark encounters* in the United States in recent years and the public is worried.

Lesson Concept

Develop an argument based on evidence from text and investigations about the cause and effect of magnetic fields produced from the electrical currents from REMUS on white sharks.

Investigative Phenomenon

White sharks can detect REMUS.

Standards

Refer to Appendix 8.5 for NGSS, CCSS (ELA and Math), and California ELD standards.

*Encounters include sightings and census estimates, as well as physical interactions between humans and sharks.

Storyline Link

Prior to this, students have learned about REMUS and how it is deployed to study the behavior of white sharks. Additionally, they learned that electromagnetic reception was the primary method that sharks use to sense the world around them, leading students to wonder if white sharks are bothered by REMUS.

In this lesson, students will construct claims about the ability of white sharks to detect the electric and/or magnetic fields produced from REMUS. Students will investigate the strength of a magnetic field that is produced by a current and how this magnetic field can interact with an additional magnet to create a motor. To do this, students plan and conduct an investigation to understand how fields are produced, deciding on variables and measurements to be recorded, and utilize their understanding of modeling complex and microscopic structures and systems to help them visualize how their function depends on the composition and relationship among parts. They also analyze many complex natural structures and systems to determine how they function and apply understanding that structures can be designed to serve particular functions by taking into account properties of different materials. Students build on their understanding of magnetic fields by engaging deeply in arguing from evidence, and compare and critique arguments on the same topic, provide and receive critique, and use evidence and scientific reasoning to refute an explanation.

In the next lesson, students will learn how tags use acoustic (sound) and radio waves to transmit to a receiver such as REMUS.

Throughout the lesson, a flag (▶) denotes formative assessment opportunities where you may change instruction in response to students' level of understanding and making sense of phenomena.

Time

220 minutes

Part I	10 minutes	Engage
Part II	120 minutes	Explore
Part III	90 minutes	Explain

Materials

Whole Class

- ❑ Document camera
- ❑ *How Do Sharks and Rays Use Electricity to Find Hidden Prey? Deep Look* video, https://www.youtube.com/watch?v=JDPFR6n8tAQ

Per Group of 4

- ❑ D cell battery or 9-volt if more power is needed (at least 1, but enough for each group preferred)
- ❑ Battery holder (at least 1, but enough for each group preferred)
- ❑ 2 large paper clips (for each battery)
- ❑ 2 rubber bands (for each battery)
- ❑ Magnetic enamel wire, 3 one-meter pieces (at least 1, but enough for each group preferred)
- ❑ Magnets (either two of different strengths, or three, in which case they'd put two together to make one strong magnet) (at least 1 set, but enough for each group preferred)
- ❑ Sand paper
- ❑ Compass (at least 1, but enough for each group preferred)
- ❑ Wire, about 50 cm, stripped at both ends, 20 gauge or above (at least 1, but enough for each group preferred)
- ❑ 8.5.G1: Snout Goo May Help Sharks Sense Prey
- ❑ 8.5.G2: Scientists Repel Sharks—to Save Them
- ❑ 8.5.G3: A Shark's Sixth Sense
- ❑ 8.5.G4: A Biological Function for Electroreception in Sharks and Rays
- ❑ 8.5.G5: Take a Position (This could be placed in a sheet protector for use with multiple classes.)

Individual

- ❑ Science Notebook
- ❑ 8.1.H2: Scientist Communication Survival Kit (from Lesson 8.1: Shark Encounters)
- ❑ 8.1.H3: My Shark Encounter Claim Chart (from Lesson 8.1: Shark Encounters)
- ❑ 8.1.H4: Crosscutting Concepts for Middle School Students (from Lesson 8.1: Shark Encounters)
- ❑ 8.5.H1: Motor Apparatus
- ❑ 8.5.H2: Observation Checklist

Teacher

- ❑ 8.5.R1: Rubric for Written Scientific Argument

Advance Preparation

1. Preview the video *How Do Sharks and Rays Use Electricity to Find Hidden Prey? Deep Look.* (Step 3 of Procedure)
2. Make one copy of each of the following articles for each group: **8.5.G1: Snout Goo May Help Sharks Sense Prey**, **8.5.G2: Scientists Repel Sharks—to Save Them**, **8.5.G3: A Shark's Sixth Sense**, and **8.5.G4: A Biological Function for Electroreception in Sharks and Rays**. (Step 4 of Procedure)
3. Duplicate **8.5.H1: Motor Apparatus** and gather materials to make a simple motor. (Step 9 of Procedure)
4. Duplicate **8.5.G5: Take a Position** (one for each group) and place in a sheet protector to use with multiple classes, if desired. (Step 10 of Procedure)
5. Duplicate **8.5.H2: Observation Checklist** for each student. (Step 13 of Procedure)

Procedure

Part I

Engage (10 minutes)

Construct an initial explanation for how the white shark detects electric or magnetic fields, causing the shark to sense REMUS.

TEACHER NOTE

It is acknowledged that in this lesson, we are actually looking at how the evidence is NOT adequate to afford students the opportunity to question what other information they will need to go further in their understanding.

1. Start the lesson by revisiting student questions generated at the end of Lesson 8.4: REMUS. Draw attention to any question students had about the shark being attracted to or bothered by REMUS as a way to help students make sense of the investigative phenomenon.

   Examples of student questions from Lesson 8.4:

   How does REMUS use sound waves to communicate with the transponder?

   Does the shark use its electro-reception to sense the navigation and communication systems of REMUS?

   What senses is the shark using to home in on REMUS?

2. Inform the class that, for now, we will consider those questions around the shark sensing REMUS. (Other questions may be explored in later lessons.) Ask students to then recall from Lesson 8.4: REMUS the different types of senses that sharks have. Ask students to discuss the following as a group and record ideas in their Science Notebook and consider what might influence how a shark senses REMUS.

   Ask students, “What would we need to consider in order to determine if a shark can sense REMUS? What questions do we need to answer in order to get the information we need?” Encourage groups to use **8.1.H4: Crosscutting Concepts for Middle School Students** (from Lesson 8.1: Shark Encounters), and to help generate questions informed by the On-Target column for Cause and Effect.

   ▶ If groups are struggling, ask the following questions to help redirect their thinking:

   - Which sense do you think might be the most sensitive (useful to sharks underwater)?
   - Which sense do you think white sharks use the most?
   - Predict which sense you think is the primary cause of a white shark to be attracted to or bothered by REMUS.

TEACHER NOTE

There are two plausible factors at play—one is that the white shark is sensing the presence of REMUS, and the other is the predatory/territorial behavior of the white shark. We will focus this lesson and line of questioning on the sensory behavior of the white shark.

3. At this stage, students have some information on shark senses and most probably think that the sharks' electroreception is what attracts the shark to REMUS, but some are unsure. A brief discussion with the class about this should lead to the conclusion that they need more evidence to address this. ▶ Ask probing questions to move thinking until students are in agreement that they need more evidence to address this.

    a. To help students get more evidence and insight into how shark electroreception works, show the students the PBS Digital Studios video, *How Do Sharks and Rays Use Electricity to Find Hidden Prey? Deep Look*, which focuses on the shark's ability to sense using the ampullae of Lorenzini (electroreception). Ask students to record any information in their Science Notebook that helps them better understand how a shark (which is closely related to a ray) can locate something using electricity.

    b. Following the video, take the opportunity to ask students to reference **8.1.H4: Crosscutting Concepts for Middle School Students**. Take a few minutes to model use of the Structure and Function concept with information from the video as inspiration, using a similar discussion pattern as was done previously for Patterns in Lesson 8.1: Shark Encounters, Step 7.b. (Consider what the structure of the ampullae of Lorenzini lend to a particular function.)

    c. After practicing with Structure and Function, revisit the student question (or version thereof), "How does a white shark sense REMUS?" Ask students to construct a *tentative* explanation in their Science Notebook. (Let students know they will be adding to this over time.) Their explanation should include the following:

        - Use an On-Target question from Cause and Effect to frame the explanation.
        - Consider whether the evidence is adequate for the explanation (do a check for relevancy and sufficiency) and identify a way to address any additional information that may be needed.

    ▶ Guide students who need support to create a graphic organizer for themselves, identifying evidence they have first, then generating a claim followed by reasoning—which can include discussion of needed information.

TEACHER NOTE

The introduction to this lesson is intended to play off of the student realization in Lesson 8.4: REMUS that REMUS has electrical components, which a shark may be attracted to. Later in this lesson, students will also discover that those electrical components can generate magnetic fields (a non-contact force, which specifically targets the DCI for this grade). Students previously explored the idea of a non-contact force (gravity) in 5th grade (PS2.B), but didn't call it a field yet. At this stage in the lesson, students are ready to apply the idea that magnetic non-contact forces act in a field. ▶ To help students with this transition of words, you can do a simple demonstration with a bar magnet (protected by plastic) and iron filings.

Students can easily see the filings interact with the magnet, visualize a "field" around the magnet, and see that the field force weakens as the magnet gets farther from the filings.

The context of REMUS provides students the opportunity to ask their own questions and work like a scientist to answer them, although many scientists don't think sharks are as attracted to magnetic fields as they are electric fields (and bear in mind, there is still a lot of uncertainty around this). To foster student sensemaking and opportunity to critically analyze evidence, we do allow students to go down a "blind" alley, thinking the magnetic components may attract sharks.

Procedure

Part II

Explore (120 minutes; three class periods)

Carry out an investigation to determine the effect of electrical currents to produce magnetic fields.

Part II A

4. As students identify areas where additional information may be needed in order to have a strong explanation, let them know you have readings that may be useful. Point out also that the Ocean Portal website they used in Lesson 8.4: REMUS referred to electric fields as well as magnetic fields, so you have found some articles that will discuss both. Arrange students into groups of 4 and give each student in the group one of the following articles: **8.5.G1: Snout Goo May Help Sharks Sense Prey**, **8.5.G2: Scientists Repel Sharks—to Save Them**, **8.5.G3: A Shark's Sixth Sense**, and **8.5.G4: A Biological Function for Electroreception in Sharks and Rays.**

Write the following codes on the board for the students to use as they read their article. Have them underline and code the following:

- "SA": Shark Anatomy—basic information about the structure/function of a shark
- "EE": Electrical Evidence—evidence that supports an understanding of how sharks are influenced by electric fields
- "ME": Magnetic Evidence—evidence that supports an understanding of how sharks are influenced by magnetic fields

Differentiation: At your discretion, put students into expert groups if they need peer support while working through the readings. Make sure that students needing language support are focusing on the content of the article rather than words that are unclear. Ask students to skim their article and highlight any words whose meaning is uncertain. Before students read the articles, offer to have students look up the meaning of highlighted words and/or as a whole class go over words that might cause some confusion or prevent them from moving forward with the reading.

5. When students have completed their reading, arrange students into expert groups with others that read the same article. Record the following on the board for students to see:

   Sharks are influenced by electric fields.

   Sharks are influenced by magnetic fields.

   Sharks are influenced by BOTH magnetic and electric fields.

   a. Ask students, in their expert groups, to compare their coding and discuss which claim they think their evidence supports best and why. Encourage students to record this discussion (especially evidence identified) in their Science Notebook.

   b. Students return to their home group and share their expert findings with their group. (Each student should have read a different article.)

      - Direct students to share what they found. Emphasize that everyone will have a chance to share before anyone can discuss or ask questions about how their evidence supports the claim they picked. During sharing, encourage students to record a couple of "big ideas" from each report.
      - After groups have shared, have a brief class discussion asking students to recall what is required for something to be considered quality evidence and a quality source.
      - Then invite groups to hold a discussion on the reading. Direct students to ask questions about the evidence of others, making sure to ask them about the source of the material. What makes for quality evidence? Why would one claim be preferred over another? Encourage students to add anything they feel is important from the discussion to their Science Notebook.

- Ask groups to then come to consensus on which claim their evidence best supports (which one best addresses the question). ▶ If there are students who need help, guide groups to recall that that their conversation needs to consider both the quality of the evidence that was gathered and discussed, as well as which claim (sharks are influenced by electric fields, or sharks are influenced by magnetic fields) had the fewest counters to said evidence (rebuttal). Students can make additional notes in their Science Notebook about which claim they are supporting and any subsequent evidence.

During discussions, encourage students to use discussion norms such as wait time, encouraging others to say more, asking for evidence, paraphrasing or repeating, adding on, etc.

TEACHER NOTE

The articles (8.5.G1–8.5.G4) were intentionally chosen from a wide range of sources, from a transcribed radio interview to an academic article. The reading levels of the articles range from 6th grade through high school. It may be best to arrange that students receive articles that are most appropriate for their reading levels. In case differentiation by reading level is needed for students, they are arranged in increasing complexity of reading level (e.g., **8.5.G1: Snout Goo May Help Sharks Sense Prey** is the easiest and **8.5.G4: A Biological Function for Electroreception in Sharks and Rays** is the most difficult).

Part II B

6. Ask students to discuss which part of REMUS they think contributes the most to the white shark being able to sense it in the water. If students do not remember the parts of REMUS ask them to refer back to their Science Notebook notes on REMUS (taken in Lesson **8.4: REMUS**, Part 7.b); they can also visit http://www.whoi.edu/osl/sharkcam again if needed.

    a. Have students make a list in their Science Notebook of the parts of REMUS in the order that they think a white shark can sense them. (A rough model can replace a list depending on student preference or need as a way to differentiate.) Have students record/identify what sense they think the white shark is using to detect the respective parts they identified, and have the students pay particular attention to electroreception. ▶ If students do not automatically do this, encourage them to think about internal components as well as external; for example, if students identify the propeller, ask what makes the propeller work (internal motor).

b. Ask a few students to share their lists/models with the class. Be sure to choose one student that identified a motor.

TEACHER NOTE

The next part of this sequence will focus on building a simple motor for better understanding of the scientific properties that govern the function of a motor and to establish the connection between electricity and magnetism. For your reference, the actual motor used within REMUS is extremely complex, but we are keeping it simple to build student understanding of magnetic fields in context.

7. Establish that students are going to focus on just one of the aspects of REMUS they identified, the motor, and how it uses electricity (and, as students will soon discover, magnetism).

   a. To first establish the connection between electricity and magnetism and to introduce the idea that an electric current creates a magnetic field, have students work in groups to create an electric current by connecting the ends of a long straight wire to each end of a D cell (or 9-volt) battery and lay the wire flat on the table. This creates a magnetic field. If a student in the room already knows how to do this, allow this student to introduce the idea. If possible, have these materials for each group so each may build the circuit. Be sure to demonstrate this at the front of the room as well.

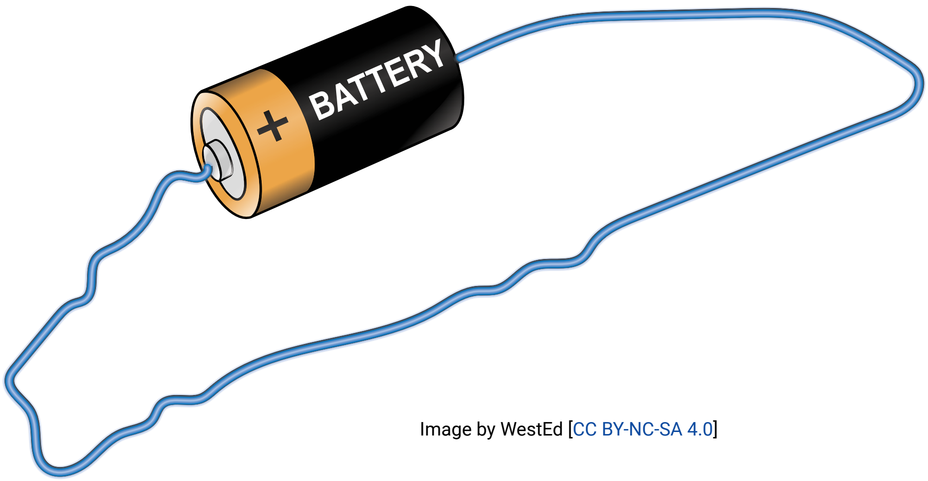

Image by WestEd [CC BY-NC-SA 4.0]

   b. Invite a student from each group to bring a compass up to the wire in several locations. Students can also do this at their tables if materials are available, but focus the conversation from the front of the room. Ask students to record observations in their Science Notebook. If possible, recreate the set-up under a document cam so there is opportunity for group discussions when manipulating the set-up. Encourage students to try out several things. (Make sure that students are bringing the compass to both sides of the wire and different distances from the wire.) Students should observe the following phenomena:

- The needle of the compass will spin when brought close to the wire.
- The needle of the compass will spin in different directions depending on which end of the wire it is near.
- The rate of spin of the compass needle will change depending on how far it is located from the wire.

c. Put the compass away and ask another student to bring a small magnet close to the wire. Students can also do this at their tables if materials are available, but focus the conversation from the front of the room. Ask students to make additional observations of the interaction between the wire and the magnet.
▶ If students are struggling, the following questions can help to guide students to build understanding of and explain the phenomenon:

- What is the effect of holding a magnet near the wire?
- Are the wire and magnet attracting or repelling?
- Is there a way to change the interaction (from repel to attract or vice versa)?
- Does the distance between the magnet and the wire change the strength of the attraction/repulsion?

(For teacher reference, when an electric current travels through a conductor, in this case a wire, a weak magnetic field is produced by that current. The magnetic field produced will deflect the compass needle. The arrow of the compass will point in the direction of the magnetic field.)

TEACHER NOTE

If there is a way to allow the wire to be perpendicular to a surface where the compasses are located, students can observe that the needle of each compass actually points to the compass next to it in a circle around the wire. While it is only necessary for students to understand that an electrical current produces a magnetic field, it is a nice "next step" for students to see that there is a pattern to the magnetic field that is produced. If the strength of the current is not enough to produce visible changes of the compass direction, this can be addressed by using a 9-volt battery instead of a D cell battery. Additionally, students could make an electromagnet, which will produce a stronger magnetic field. In either case, some safety precautions should be taken if a stronger battery or electromagnet is used, as they heat up quickly. Students can use erasers as an "insulator" between their fingers and circuit components to avoid feeling heat.

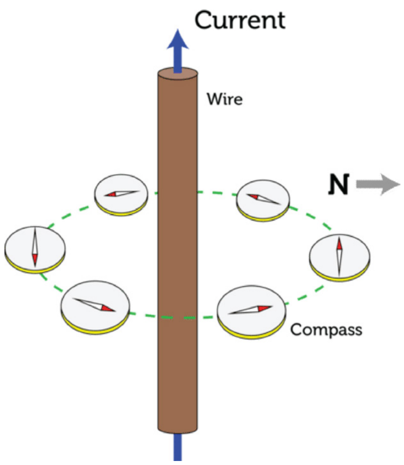

Image by Christopher Auyeung via CK-12 Foundation [CC BY-NC 3.0]

8. Following these observations, let students know they will now be designing their own investigation to help answer some of their questions. Have a discussion with students about what constitutes a fair test and variables (as this should be prior knowledge). ▶ If students struggle, you can prompt them with one or more of the following questions or statements:

   - If we want to know if something has had an effect, what would be a fair test?
   - Why should we test only one thing at a time?
   - Are there aspects of a test that don't change? Why is it important to have those?
   - When students begin describing the parts of the investigation that "we" manipulate, confirm that these are called *independent variables*.
   - When students describe things that change because of that manipulation, confirm. that these are called *dependent variables*.
   - When students describe something we would keep constant, confirm that this is a *control*.

9. Distribute **8.5.H1: Motor Apparatus** and materials to students. Ask students for their ideas about motors—why we need them, why we test them, and how testing motors can help us explain why the white shark attacked REMUS.

   a. Ask student groups to come up with four different variables to test for the motor apparatus. Here are some of the variables that students might elect to test:

      - Number of turns
      - Diameter of the turns
      - Strength of the magnets
      - Distance the magnet is away from the coiled wire
      - Gauge of the wire
      - Strength of the battery (This might require changing the apparatus to accommodate the new battery)

      TEACHER NOTE

      The following variables would be more suited to highly motivated students as they are either not as directly observable or require a more sophisticated understanding of the variable as to how it is effecting change; diameter of the turns and gauge of the wire.

   b. Once students have established what they would like to test and begun planning their investigation, ask them to record the following in their Science Notebook. Consider allowing students who need literacy support to work in pairs; later you can make a copy of the work completed for the other student to add to their Science Notebook.

- What question of theirs are they testing? (This doesn't necessarily need to be a formal research question; it may simply be a question that emerged in the discussion above that the group would like to test.)
- Explain their test; give a brief description of what they will do.
- List variable(s) (independent and dependent) and control(s).
- Specify the type of data they will measure and how.
- Make a prediction of what they think will happen (with rationale).
- Record observations. (How will they record observations/data?)

Students can collaboratively discuss, but each should maintain their own record of the plan in their Science Notebook, in addition, students are realistically doing several tests; this is intended to be a "rough" plan in their Science Notebook to track what they are doing and what they observe.

Encourage highly motivated students to develop even more tests.

c. Once groups have recorded their plan, allow access to materials to begin testing their plan. Instruct students to record their findings in their Science Notebook.

d. After groups have done their investigations and had time to make meaning in their Science Notebook (via small models and/or notes), have a class conversation about how the two magnetic fields were interacting. Depending on the types of investigations that students conducted, some of the questions generated might sound like the following:

- Were the magnetic fields attracting or repelling? What is your evidence?
- What caused the motor to spin slower/faster?
- How do you think this compares to the motor in REMUS?

e. Ask students to record any aha moments about magnetic fields in their Science Notebook and what phenomena they could predict using the cause and effect relationship they just discovered. Inform students that this will be used for sticky note feedback (as described in Lesson 8.2: Fossil Evidence).

Procedure

Part III

Explain (90 minutes; two class periods)

Communicate an argument while citing evidence of the cause and effect that magnetic fields produced by the electrical currents from REMUS have on white sharks.

10. Distribute a copy of **8.5.G5: Take a Position** to each table to help students make sense of the phenomena. Ask students to read the thoughts of the four students in the handout and to think about which student's thoughts they are most aligned with.

    a. Ask students to share with their group which thoughts on the handout they are most aligned with. As students discuss, have them question each other about the following:

       - What evidence do you have to support that claim?
       - What would be a rebuttal to that claim (what could refute it)?
       - What evidence do you have that supports a refute to the claim?
       - What other evidence or experiences from your lab exploration would make your claim stronger?
       - What On-Target component of Patterns or Cause and Effect, found in **8.1.H4: Crosscutting Concepts for Middle School Students** (from Lesson 8.1: Shark Encounters), helps strengthen the argument?

11. Ask students to review their original claim in their Science Notebook (from Step 3) and their claim about what is actually sensed (from Step 5) and consider all information to generate a full explanation to address the question: *How does a white shark sense REMUS?* Ask students to incorporate at least On-Target components of Pattern or Cause and Effect as a central frame to their argument. (At this stage, encourage paragraph form. Remind students of components of an explanation and/or use a scaffold for students who need to pre-organize their work.)

    Claim: An answer to your question

    Evidence: Examples of data that support the claim (observations, numerical data, information from reading, and model outputs)

    Reasoning: Description of how or why the evidence supports the claim using scientific ideas (This is an efficient place to incorporate Pattern or Cause and Effect.)

    Consider allowing students who need literacy support to work in pairs on an explanation; later you can make a copy of the work completed for the other student to add to their Science Notebook. Alternatively, allow students to do this work in their native language.

A project of CA NGSS K–8 Early Implementation Initiative.

12. Students should reflect (share explanations as a group) and ready their notes to prepare for a Science Seminar on the following day.

13. Hold a Science Seminar to evaluate revised claims that connect understanding of magnetic fields to what students previously learned about REMUS (informed by their explanations created in Step 11 as well as discussions in Steps 5–6) and to think about what the causes are for the white shark to act in the way that it does towards REMUS:

    Sharks are influenced by electric fields generated by REMUS

    Sharks are influenced by magnetic fields generated by REMUS

    a. Divide students into two groups, an inner and outer circle. The inner circle will be the first group to discuss; the outer will be the second group to discuss.

    b. Students who are seated in the inner circle participate in the discussion:

        - One student poses the question “Does the white shark sense REMUS, and if so what is the cause?”
        - The student seated to this person’s right, states their claim, evidence, and reasoning. (Given the length of these, this can also be projected as the student states it.)
        - Students take turns stating whether they agree or disagree with the proposed claim, evidence, and reasoning and, most importantly, stating the reasons for their thinking. They may use their own claim, evidence, and reasoning statements to add to the discussion.
        - Students do not need to raise their hands, but they should not interrupt.

    c. Students who are in the outer circle are observers. Give each observer a copy of **8.5.H2: Observation Checklist**.

        - Each student in the outer circle is assigned to a student in the inner circle for whom they will record data by completing **8.5.H2: Observation Checklist** as a way to give feedback on their designated participant’s performance.
            - How often did the student participate?
            - Did the individual participate voluntarily, or did he/she need to be prompted?
            - What was the strength of the claim as supported by evidence? (strong/solid/moderate/weak)
            - How effectively did this student incorporate Pattern or Cause and Effect? (strong/solid/moderate/weak)
            - Choose the word that best describes the individual’s ability to build on ideas (strong/solid/moderate/weak)

d. After about 10 to 15 minutes, have students switch roles.

e. After both groups have participated, allow students time to reflect in their Science Notebook:

- What went well? Why?
- What could be improved? Why?
- What did they agree with? Why?
- What did they disagree with? Why?
- What evidence was presented that made them question their claim?

*Note: Science Seminar from NGSS Rollout #3. CA NGSS Collaborative, 2016. Adapted with permission

14. As groups finish, ask them to revisit **8.1.H3: My Shark Encounter Claim Chart**, from Lessons 8.1–8.4 and add any new information that could be used to support any of the claims and subsequent evidence and reasoning.

15. As a possible follow-up, ask students to support or refute the following argument to be used as a summative assessment:

    a. Claim: “Sharks are not able to detect REMUS.” Prompt: Support or refute this claim by providing an explanation supported by evidence and reasoning using cause and effect as a central frame.

    b. See **8.5.R1: Rubric for Written Scientific Argument**, for scoring guidance.

Accommodations

When showing a short video, it's often helpful to students to watch the video once to get a sense of the purpose. Showing the video a second (and sometimes third) time allows students to focus on important details that can be recorded in their Science Notebook and discussed.

To accommodate students who need help with reading tasks, ask the class to skim the article first, and identify any words for which they might want clarification. Clarify the directions, then ask students to do a group read (have one person in the group read the article out loud), but encourage students to withhold group discussions until everyone has had a chance to do their own thinking and make notes in their Science Notebook first, then discuss with their group, and revise Science Notebook work accordingly.

By seating students in groups (groups of 4 work well) and encouraging regular conversation, students have time to interact more with content and naturally help those that need more support. Use of the **8.1.H2: Scientist Communication Survival Kit** (from Lesson 8.1: Shark Encounters) helps to make sure that students who don't feel comfortable sharing (often because of language, literacy level, uncertainty of content knowledge, etc.) are prompted to do so in a supportive way.

Use of a sense-making Science Notebook supports student language development, conceptual development, and metacognition. Students should be prompted to use their Science Notebook for

- ❑ prior knowledge of phenomena,
- ❑ exploration of phenomena and data collection,
- ❑ making sense of phenomena, and
- ❑ metacognition.

By writing about topics in their Science Notebook BEFORE discussing, second language learners and low language students can gain confidence and organize their thoughts before speaking in front of a group. Also, sharing ideas in a small group throughout the rest of the lesson lowers the affective filter of low language students. Having students work in teacher-selected partnerships or groups allows you to match students in a way that both are being supported. Advanced students have the opportunity to explore additional questions that arise.

Consider providing sentence frames for low literacy and second language learners. The use of graphic organizers can help struggling students manage Science Notebook work.

As this lesson is rich with discourse opportunities, consider pairing second language learners with a "language broker" (another student who is bilingual in English and the student's home language) to allow these partners to first discuss ideas in their home language. Monitor this paring and provide additional language support as needed.

For students new to a socratic seminar and in need of speaking support, review the discussion norms and questions from "Socratic Seminars in Science Class" (Chowning, 2009). Consider including additional talk moves (for ideas, see *Talk Science Primer*, Michaels and O'Connor, 2012). As students begin to share ideas, use specific prompts such as, “Can you say more about that,” “What do you mean by that,” and “Can you give an example.” Asking another student in the seminar to repeat what the speaker said, or to add on to what the speaker said is also helpful. Once students understand the structure of the seminar, these prompts should come less from you and more from the students participating in the seminar.

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Carl D. Hopkins discusses Adrianus J. Kalmijn’s 1971 paper entitled ‘The electric sense of sharks and rays’. A copy of the paper can be obtained from http://jeb.biologists.org/cgi/content/abstract/55/2/371

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Toolbox Table of Contents

Snout Goo May Help Sharks Sense Prey

This 'jelly' relays the electric currents that are created as prey move

Emily Conover
June 30, 2016

Image via Wikimedia Commons [Public Domain] Modified by WestEd.

Tests of jelly extracted from a bonnethead shark (such as this one) and two rays show that it may help these fish sense their prey—even in murky conditions.

Sharks appear to have a sixth sense that helps them locate prey in murky ocean waters. These fish rely on special electricity-sensing pores on their heads and snouts. The pores were first described in 1678. Even now, however, scientists aren't quite sure how they work. But new data have just brought them a step closer.

These pores are known as ampullae (AM-puh-lay) of Lorenzini. They connect to cells that sense electric fields. And that can be useful as the movement of nearby prey emit such fields.

Those pores are filled with what might best be thought of as shark jelly. It's a mysterious goo that is thick but clear. Scientists had suspected the jelly might play some role in detecting prey, but they weren't sure just how.

So Marco Rolandi of the University of California, Santa Cruz and his engineering colleagues have just analyzed this goo. They squeezed some of it from the pores of a bonnethead shark and two skates (the "big" and longnose species).

Protons are a type of positively charged subatomic particle. Their movement can create an electric current. Many good proton conductors occur in nature. (One, for instance, exists in squid skin.) Rolandi's team investigated whether the shark jelly, too, could transmit protons.

Snout Goo May Help Sharks Sense Prey (continued)

And indeed it can, the scientists now report. Protons move well through the jelly and transmit an electric current. They shared their findings May 13 in *Science Advances*.

Shark jelly is, in fact, the living world's best proton conductor. Engineers have come up with a synthetic compound that is 40-times better. But other than that material, known as Nafion, nothing comes close to the stuff sharks make. So it appears that shark jelly may allow these fish to sense very weak electric fields—picking up on teensy hints that lunch may be swimming nearby.

Power Words

electric current	A flow of charge, called electricity, usually from the movement of negatively charged particles, called electrons.
electric field	A region around a charged particle or object within which a force would be exerted on other charged particles or objects.
engineer	A person who uses science to solve problems. As a verb, to engineer means to design a device, material or process that will solve some problem or unmet need.
gel	A gooey or viscous material that can flow like a thick liquid.
prey	(n.) Animal species eaten by others. (v.) To attack and eat another species.
proton	A subatomic particle that is one of the basic building blocks of the atoms that make up matter. Protons belong to the family of particles known as hadrons.
rays	(in biology) Members of the shark family, these kite-shaped fish species resemble a flattened shark with wide fins that resemble wings.
shark	A type of predatory fish that has survived in one form or another for hundreds of millions of years. Cartilage, not bone, gives its body structure.
subatomic	Anything smaller than an atom, which is the smallest bit of matter that has all the properties of whatever chemical element it is (like hydrogen, iron or calcium).
synthetic	An adjective that describes something that did not arise naturally, but was instead created by people. Many have been developed to stand in for natural materials, such as synthetic rubber, synthetic diamond or a synthetic hormone. Some may even have a chemical makeup and structure identical to the original.

Emily Conover, *Science News for Students*, June 30, 2016. Used with permission.

Scientists Repel Sharks—to Save Them

April 04, 2012 • 12:00 PM CDT
Reporter Ari Daniel, Host Marco Werman

It sounds like a plot device from a comic book: a simple substance that can make the powerful weak. But it's not Kryptonite. An American chemist says he's found a substance—several, in fact—that can repel some of the most fearsome predators in the ocean, and he wants to use his discovery to protect them. Reporter Ari Daniel Shapiro of our partner program NOVA has the story.

Eric Stroud stands on a pier on the island of North Bimini in the Bahamas. He looks down into the turquoise water.

"The current is ripping through here right now," he says. "The tide is going out. So any scent that's put here goes right to the outside of the channel, and that's where pretty much the big sharks are right now."

Stroud is setting up an experiment. He unwraps twenty pounds of frozen sardines, drops them into a mesh bait bag tied to the pier, and tosses the bag into the water. He's hoping to attract a large bull shark.

"It's a fairly dangerous shark," he explains. "It can be aggressive, especially when provoked or cornered."

If a bull shark does show up, he'll throw a large baited hook into the water. But it's not your typical fishhook. In fact, if all goes well, this hook won't catch any sharks.

A Passion for Repellents

For more than a decade, Stroud has been working to develop shark repellents.

Back at the Bimini Biological Field Station, where he has come from his home in New Jersey to test his latest ideas, he explains what led to this unusual career choice.

Stroud, 38, used to work fulltime as a chemist in the pharmaceutical industry. Then, in the summer of 2001, he and his wife went on a cruise to Bermuda.

"We hit bad weather, and we were trapped in a cabin, and on the news was shark bite after shark bite," he says. "It seemed like everyone that stepped in the ocean in Florida was getting attacked by a shark that summer."

Scientists Repel Sharks—to Save Them (continued)

That's when his wife suggested he turn his talents to developing shark repellents. When they got home, he set up several kiddie pools in his basement, and he filled them with small sharks.

He watched how the sharks fed, swam, and behaved. Then, one day, he accidentally dropped a large magnet from his workbench. He noticed some small nurse sharks dart away.

"That night, we put magnets into the tank and couldn't believe [that] the nurse sharks were just extremely distressed and stayed away from them," he says.

Stroud had discovered that magnets repel sharks.

He demonstrates the effect in a seaside pen in the Bahamas. His field assistant, T. J. Ostendorf, captures a small lemon shark and slowly rotates it onto its back underwater. This puts the shark into a sleep-like state.

Then Stroud takes a magnet and spins it as he moves it toward the shark. The shark immediate[ly] bends away from the magnet—"like it's another magnet," says Stroud.

Ampullae of Lorenzini

Sharks possess electrical sensors, called the ampullae of Lorenzini, that look like tiny freckles on their snouts. Biologists believe sharks use these sensors to detect the heartbeats of their prey and to navigate using the Earth's magnetic field.

Stroud suspects the spinning magnet overwhelms those electrical sensors.

"It's probably something like a bright flashlight across your eyes," he says. "It's just temporarily blinding, and you're startled. And it's not pleasant."

Stroud made his discovery in 2004. It helped him jumpstart a company he'd founded, called SharkDefense, that aims to develop and commercialize shark repellents.

He and his team tested other substances, and they found that some non-magnetic metals also interfere with a shark's electrical sensors. Particularly effective are rare-earth metals like samarium, neodymium, and praseodymium.

Stroud's original plan was to develop repellents to protect people, and he's working on ways to do that. For instance, he and his partners are researching a magnetized underwater fence that might keep sharks away from swimmers.

But his main focus has switched to using repellents to protect sharks.

Scientists Repel Sharks—to Save Them (continued)

Many shark species are being overfished, and some are endangered. One reason is that fishermen trying to catch other fish often catch sharks by accident. Stroud wondered—what if he could produce fish hooks that catch fish like tuna and halibut as usual, but that sharks avoid?

"We realized we could magnetize the fishing hook, and we can coat it with a rare earth metal," he says. "It looks just like a regular hook, and we get the benefit of two repellents at the hook."

A Newfangled Hook

Several countries are now testing his so-called SMART Hooks to see if they work. Some tests show a 60 to 70 percent reduction in the number of sharks caught.

Stroud received an award from the World Wildlife Fund for his invention, and he's hoping to sell it commercially before long.

In the meantime, he continues to refine the design, trying new combinations of metals and magnets, and observing how they affect different types of sharks.

And that's why he's come to the pier on North Bimini Island to chum the waters for a large bull shark. He wants to test a magnetized fishhook wrapped in a magnesium foil.

A couple of eagle rays and barracudas swim by, but there's no sign of a bull shark. His hook sits on the pier.

"Sometimes nothing happens quickly in shark repellent research," he says with a smile.

Stroud waits for more than an hour. "We have to try again," he says as he pulls the bait bag in and dumps the sardines onto the pier. He calls it a day.

Eight years after the chance discovery in his New Jersey basement, Stroud has come to accept that product development is a slow process. But his attraction to repellents runs deep, and he says the sharks keep luring him back.

Ari Daniel. The World. April 4, 2012. Reproduced with Permission.

A Shark's Sixth Sense

By: Malcolm A. MacIver
July 31, 2009

In honor of the Discovery Channel's Shark Week, we're taking a look at the electrifying capabilities of sharks and fish that help them find their way (and even their dinner)!

Resident expert Malcolm MacIver, assistant professor of biomedical engineering at Northwestern University's McCormick School of Engineering, explains.

We usually think that electricity and water don't mix, but I hear that some underwater creatures use electric signals to navigate or find food. Is this true?

You're correct—certain kinds of fish and other animals, like sharks, can use electric signals to detect objects. This is called electrolocation. There are two forms of electrolocation, active and passive. It's like the difference between sensing something with radar, which is active, versus just listening to something, which is passive.

How does active electrolocation work?

Using active electrolocation, an animal emits a weak electric field, allowing it to sense the presence of nearby objects without actually touching them. It works in the following way: if you have a fish in a fluid, let's say fresh water, that fluid has a certain electrical resistance to it. If you put an object in that fluid with a different resistance, like another animal, it creates a distortion in the water's electrical properties. The fish's active electrosensory system detects this distortion. This ability does not extend more than a body length away, but it's very effective in that short range.

For example, on the South American freshwater electric fish I research, the black ghost knifefish, there are about 17,000 receptors covering the entire body surface. All of those sensors are like little volt meters that are picking up distortions around 1.0 – 0.1 microvolts, a millionth of a flashlight battery in voltage, caused by any objects that might be in their sensory range.

How does passive electrolocation work?

Other animals, like sharks, don't generate their own electric field. Instead, they have sensors that can pick up electric signals, which are created by every living animal in the water. This is passive electrolocation. When you go into the ocean, you have what's called a bioelectric potential around your body; sharks can hone in on that using electroreceptors. Any kind of cut in the skin increases this bioelectric potential, creating a sort of electrical spotlight and putting the animal at a higher risk of being detected. We know that sharks hunt using their extremely sensitive sense of

A Shark's Sixth Sense (continued)

smell as well – but this is mostly useful for getting in the general vicinity of potential prey. Passive electrolocation complements this blurry sensory ability so that the shark can make a precise attack.

Do sharks also use electrolocation to navigate? And if so, why?

We know that sea turtles are able to pick up both the direction and intensity of the earth's magnetic field. If you chart these two factors across the globe, in certain places you actually get a very nice bi-coordinate map – like longitude and latitude but in terms of the intensity and direction of the magnetic field. We have determined that they're able to navigate by these fields. We don't know exactly how, but we know that if we put them in a tank with big magnets, we can confuse them in predictable ways.

We don't know if the same is true for sharks. However, there's some behavioral evidence in support of the idea—for example, they go long distances in straight lines consistent with following the earth's magnetic field when there appear to be no other cues available. What we do know is that sharks have this amazing ability to sense external electrical fields such as bioelectric fields. Their sensitivity is astonishing – it's on the order of a nanovolt. If you put a flashlight battery in the ocean, there's about a nanovolt every inch or so more than a mile away from that battery. That sensitivity is almost hard to believe. It's high enough that they can detect the direction and intensity of the earth's magnetic field by sensing the internally induced currents that happen when they move through it.

Why would they need a sensory ability like this? Picture yourself out on the ocean. There are a ton of cues indicating direction—direction of polarized light, wind and wave direction, water current direction, even where bright stars are at night. The problem for a shark is that they're way, way down and they want to go a long distance. One great white shark, which was tagged with a transmitter, was shown to go from Africa to Australia and back – over ten thousand miles! So how are they going to do that without any of these things like polarized light direction or wave cues? Although far from being settled, some scientists suspect that sensing the earth's magnetic field using their electrosensory system is one trait sharks have developed to get from one place to another in the absence of other navigational indicators.

What are some of the long-term practical applications of robotics research in sharks and weakly electric fish?

Quite a few, actually. So it turns out that sensing by way of electric fields – in the way that fish do this – is relatively unexplored in engineering. If we understood how that works, we could potentially have a whole other sensory modality to work with.

A Shark's Sixth Sense (continued)

For example, if you are a roboticist who wants to bring robots into everyday home life, the number one problem you'd be trying to solve is the problem of manipulation. What do I mean? I mean gripping something. Picking something up like your newspaper, handing it to a person. Picking up a cup of coffee. That stuff is really, really hard for robots. It's a tough problem to solve.

Robots have contact sensors, which are good once you touch something. But what humans do, when we approach something to grab it, is pre-shape our grasp based on visual cues—we actually manipulate our hand so it is at least in the right general shape. Active electrolocation could allow robots to sense the shape of an object before touching it, bridging this sensory gap.

Malcolm MacIver. Department of Mechanical Engineering, Northwestern University. Reproduced with permission.

A Biological Function for Electroreception in Sharks and Rays

JEB Classics is an occasional column, featuring historic publications from *The Journal of Experimental Biology*. These articles, written by modern experts in the field, discuss each classic paper's impact on the field of biology and their own work. A PDF of the original paper is available from the JEB Archive (http://jeb.biologists.org/).

JEB Classics

A BIOLOGICAL FUNCTION FOR ELECTRORECEPTION IN SHARKS AND RAYS


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With 2 text-figures
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THE ELECTRIC SENSE OF SHARKS AND RAYS

By A. J. KALMIJN

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(*Received* 18 *March* 1971)

INTRODUCTION

In 1917 Parker and van Heusen published their historic paper on the behavioural responses of the catfish, *Amiurus nebulosus*, to metallic and non-metallic rods. They found a blindfolded *Amiurus* to be remarkably sensitive to metallic rods, regularly responding to them even at a distance of some centimetres, whereas a glass rod did not elicit a reaction until it actually touched the skin of the animal. When much of the metal was exposed to the water, the fish swam away from it; when little was exposed, the fish turned towards the rod and often nibbled it. In a series of simple but convincing experiments Parker and van Heusen demonstrated that these responses were due to the galvanic currents generated at the interface between metal and aquarium water. The same responses could be obtained by sending a weak direct current into the water via two electrodes, kept 2 cm apart. In this case approach and nibbling were called forth by a current of a little less than 1 μA and the avoidance reactions by currents of 1 μA or more.

Parker and van Heusen did not realize the significance of their results, but in fact they were studying the electrosensitivity of fishes that have – as we now know – distinct electroreceptors. Curiously enough, the electroreceptors of *Amiurus* were not identified experimentally and investigated electrophysiologically until very recently (Dijkgraaf, 1968; Roth, 1968, 1969). Even now, we can only speculate about the biological meaning of the electrosensitivity of the catfish.

Long after the work of Parker and van Heusen, in the year 1951, a new impetus to the study of the electrosensitivity was given by Lissmann. He examined the electric discharges that *Gymnarchus niloticus* and other weakly electric fish almost continuously emit, and proposed the theory that they play an essential role in an electrosensory mechanism for object location. These fish would be able to detect a nearby object of an electrical conductivity different from that of the surrounding water by appreciating the distortion it causes to their electric field. Later on, Lissmann proved *Gymnarchus* to be indeed very sensitive to purely electrical stimuli as implied by his theory, and also showed the fish to be able to discriminate between objects of only slightly different conductivity (Lissmann, 1958; Lissmann & Machin, 1958).

Lissmann tentatively regarded the weakly electric fish as evolved from a pre-electric fish without electric organs but already sensitive to electric fields. He suggested that at this early stage the electrosensitivity might have been used to detect muscular potentials of prey, predators, members of the same species, and of the animal itself. Today,

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Carl D. Hopkins discusses Adrianus J. Kalmijn's 1971 paper entitled 'The electric sense of sharks and rays'.

A copy of the paper can be obtained from http://jeb.biologists.org/cgi/content/abstract/55/2/371

The discovery of a new sensory modality in animals is of great significance in the history of biology – akin to the description of a new species of bird or primate or the unearthing of a missing link in the fossil record. In this issue we celebrate one of the key papers in the discovery of electroreception in fishes (Kalmijn, 1971), which established a biological function for the ampullae of Lorenzini in sharks and rays. It has become a citation classic for *The Journal of Experimental Biology*.

Evidence for electroreception accumulated rapidly in the period between 1957 and 1971. First, there were behavioral studies that showed that weakly electric fish from Africa and South America could communicate with conspecifics (Möhres, 1957) and 'electrolocate' hidden objects in their environment (Lissmann and Machin, 1958). Electrolocation in electric fish had much in common with echolocation in bats that were using ultrasound to find their insect prey (Griffin, 1958). These fishes could sense objects that differed in conductivity from the water even when visual, chemical and mechanical cues were obscured. Shortly after Lissmann and Machin's behavior study in 1958 (Lissman and Machin, 1958), which is also a JEB Classic (Alexander, 2006), came electrophysiological recordings from electroreceptors (Bennett, 1965; Bennett, 1971; Bullock et al., 1961; Fessard and Szabo, 1961; Murray, 1959; Murray, 1960; Murray, 1962), anatomical studies on the receptor organs (Bennett, 1965; Bennett, 1971; Derbin and Szabo, 1968; Szabo, 1965) and neurobiological studies of sensory coding (Bullock and Chichibu, 1965; Hagiwara and Morita, 1963; Hagiwara et al., 1962; Hagiwara et al., 1965a; Hagiwara et al., 1965b).

Despite this rapid progress it was still unclear how the earliest electroreceptors evolved because there had been no study of the functional role of electroreception in species lacking weak electric organs. This included the non-electric sharks, skates and rays, and catfish and, as we now know, many others (Bullock and Heiligenberg, 1986; Bullock and Hopkins, 2005; Bullock et al., 2005; Hopkins, 2009). These electroreceptive but non-electric fishes were obviously the key to solving Darwin's (Darwin, 1859; Darwin, 1872) 'case of special difficulty' – the origin of electric organs in electric eels and Torpedo rays through a series of gradual adaptive modifications. If weak electric organs were useful for both communication and active electrolocation, it was possible to conceive of the intermediate steps that would lead to the evolution of stronger and stronger electric organs. But what was the function of electroreceptors if electric organs were absent, as they are in sharks and most rays?

In 1971 in one short paper, now a JEB Classic article, Adrianus J. Kalmijn from the University of Utrecht in The Netherlands found the answer. He demonstrated that these elasmobranchs could detect natural electric fields surrounding fish that were their natural prey, that they could orient to these electric fields, and that they could accurately attack them even when their prey was visually hidden – as occurred when the flatfish *Pleuronectes platessa* was buried under the sand. They could do so, at night, and even when chemical and mechanical cues were absent. The experiments were simple and clear, and the writing was direct. Furthermore, this paper had one memorable figure – a 'story board' for the six experiments performed in the study – that sticks in your mind like a Mozart melody. It lays out the evidence for a natural function for these electroreceptors (see Fig. 1 legend). By establishing a clear natural function for electroreception, Kalmijn did what Parker and van Heusen (Parker and van Heusen, 1917) had not done in their earlier account of experiments showing that catfish respond to metallic rods and galvanic currents. Prey capture was not simply a curious perceptual response of an

A Biological Function for Electroreception in Sharks and Rays (continued)

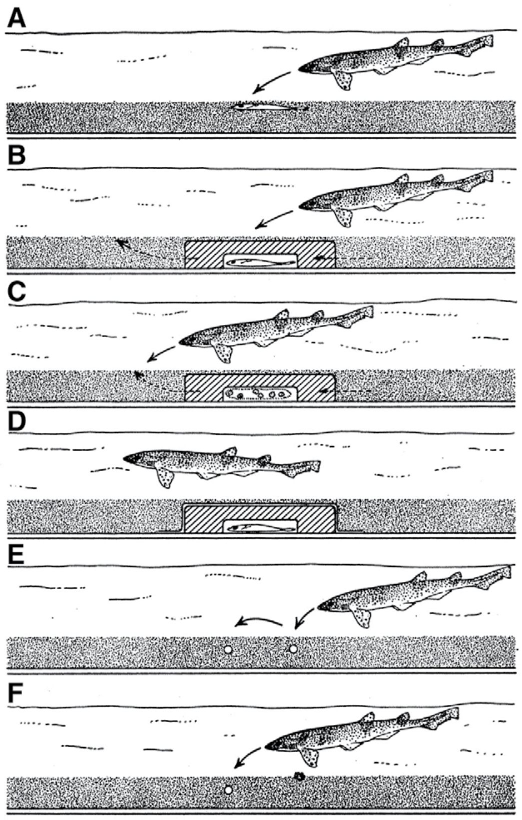

Fig. 1. Kalmijn's behavioral experiments revealed the importance of electroreception in passive electrolocation of prey (Kalmijn, 1971). The studies were conducted in captivity, and the spotted dogfish shark *Scyliorhinus canicula* detects and accurately attacks its natural prey, a flatfish, *Pleuronectes platessa*, buried under the sand (A). The shark also attacks when the flatfish is covered both by sand and a chamber molded from agar made with seawater (B). The sand blocks visibility of the prey while the agar chamber impedes mechanical cues due to water motion and limits diffusion of chemicals but it has the same electrical conductivity as the seawater. By pumping water through the chamber to an exit tube some distance away, Kalmijn tested the importance of chemical cues carried in from the water flow (Kalmijn, 1971). The shark attacks the chamber, not the outflow. Chopped fish bait under the agar chamber redirects the shark's attack to the outflow tube (C). Electrically insulating the agar chamber with thin plastic sheeting blocks the flatfish's inevitable bioelectric signals and muscle potentials and the shark is disoriented (D). As proof that the shark is guided by the electric signal, electrodes buried in the sand replace the prey, and when they are connected to a low frequency 4 μA current source emitting signals that are close in amplitude to natural bioelectric emissions (*ca.* 120 μV 5 cm^{-1}, 1 Hz sine wave) the shark attacks (E). Finally, the sharks show a preference for attacking the electrodes even if a piece of fish bait is presented on the surface (F). Reprinted from fig. 2 from Kalmijn (Kalmijn, 1971).

animal in an experimental set-up but a natural sensory response essential to its survival. Hence, it was a new sense organ.

Why was this paper so compelling, given that most of the basic anatomy of electroreceptors was known by 1971, and most of the functions already established? Perhaps it was the care with which the laboratory studies were linked to relevant field conditions, or the clarity of the figure, or the economy of the writing, which summarized data without tables or statistics.

I first met Ad Kalmijn in Ted Bullock's laboratory at Scripps Institution of Oceanography in San Diego, CA, USA, shortly after this paper was published. It was a good time to be a post-doc there, as the Bullock lab was thriving with several students and post-docs actively at work on electroreception and other aspects of comparative neurobiology. Walter Heiligenberg had just arrived to study the Jamming Avoidance Response, and Joe Bastian was trying to understand the large cerebellum of electric fish. Kalmijn was busy setting up large tanks for testing sharks and rays. He helped Eric Knudsen, a beginning graduate student, to study electroreception and the geometry of electric fields from weakly electric fish. Knudsen later made electrophysiological recordings of sensory maps for electric field vectors in the torus semicircularis of catfish. Several years later Kalmijn wrote influential papers on the use of electroreceptors in the detection of the Earth's magnetic field (Kalmijn, 1974), which he alluded to in his JEB paper; and he was influential in understanding the physics of electric and hydrodynamic fields in water (Kalmijn, 1997). It was an exciting time to work on the many aspects of this new sensory modality, and it is gratifying to see how far electric fish have come, from those early beginnings to become a great model system in neuroethology (Bullock et al., 2005).

I often return to Kalmijn's 1971 paper in my teaching. I show Fig. 1 and tell the story of how we learned the function of early electroreception in fishes.

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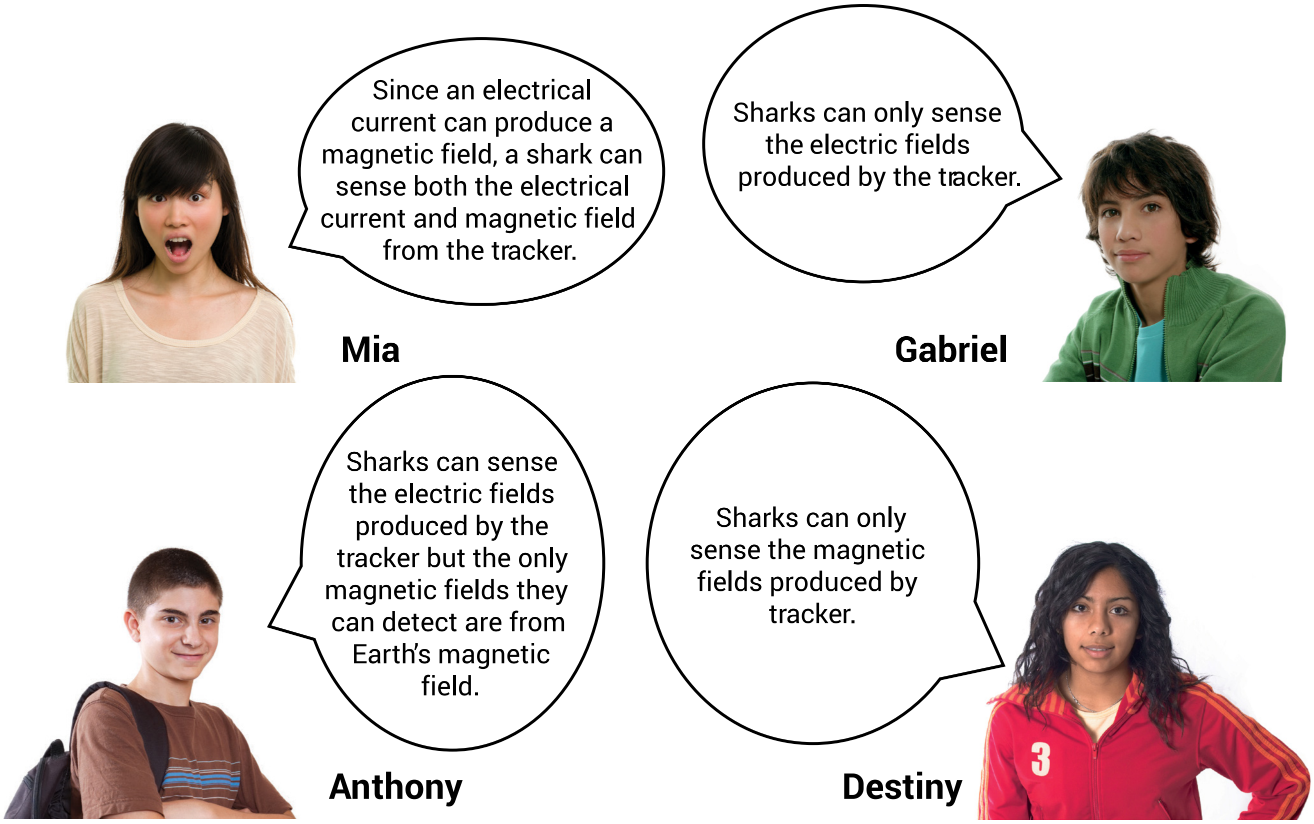
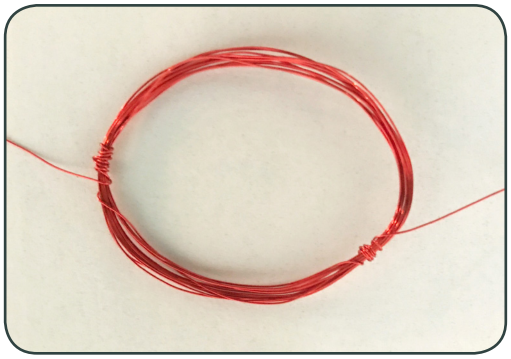
Take a Position



Motor Apparatus

To make the apparatus:

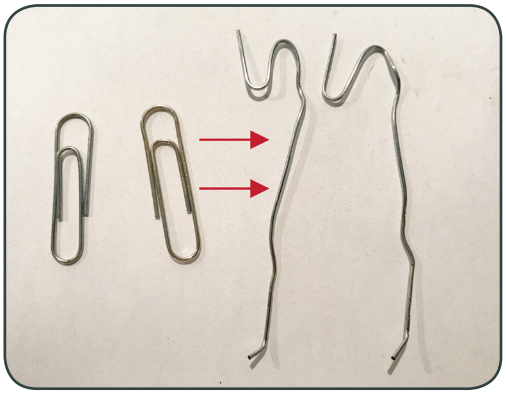
1. With a length of magnetic enamel wire, make a circle of about 20 loops. If you need help making your circle, loop the wire around a circular object, such as a paper towel tube, battery, plastic cup, or water bottle. Be sure you leave a "tail" of approximately 2 inches of wire on each side of the circle.



Steps 1 and 2

2. Wrap the two "tails" around the circle of wire several times to help the circle keep its shape and to hold the wires in the circle together.

3. Take two paper clips and unbend them to look like the ones shown in the picture. Use the unbent paper clips to hold up the circle of wire you made in the previous steps.



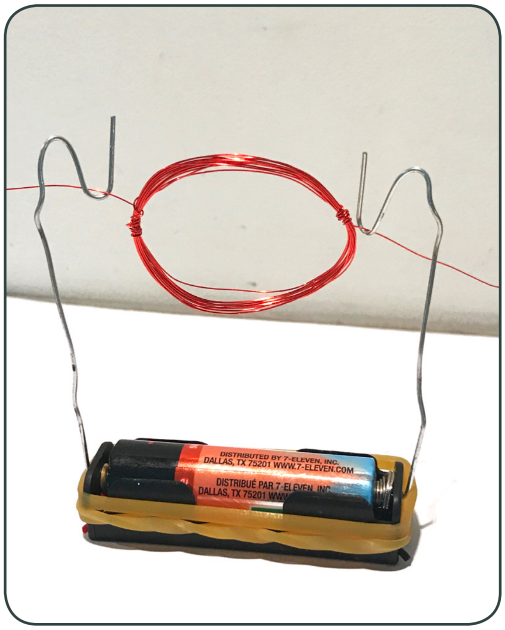
Step 3

4. Place the battery into the battery case, making sure the positive (+) end of the battery is lined up with the (+) end of the case.

5. Take the unbent paper clips and insert them through the holes on each end of the battery case.

6. Use the rubber bands to hold the paper clips in place by stretching them around the base of the battery case.

7. Use sandpaper to rub off the outer coating of each end of the wire. To do this, lay the coil flat on the desk and sand only the top of the wire on each end. If the enamel is not scraped off correctly, the motor will not work.



Steps 5, 6, and 7

Images via WestEd [CC BY-NC-SA 4.0]

Observation Checklist

Observer: ________________________

Observed: ________________________

1. How often did the student participate?				
2. Did the student participate voluntarily, or did they need to be prompted?				
	Strong	**Solid**	**Moderate**	**Weak**
3. What was the strength of the claim as supported by evidence?				
4. How effectively did this student incorporate Pattern or Cause and Effect?				
5. Which word best describes the individual's ability to build on ideas?				

Rubric for Written Scientific Argument

4	3	2	1
Claim stated addresses the question asked and strongly connects to evidence.	Claim stated addresses the question asked but weakly connects to evidence.	Claim stated addresses the question asked but does not include evidence that supports the claim.	Claim is not stated or does not address the question asked.
Sufficient evidence is used to identify patterns and relationships in a way that allows for scientific reasoning.	Some evidence is used to identify patterns and relationships in a way that allows for scientific reasoning.	Evidence is inappropriate (does not connect to claim) or interpreted incorrectly.	Evidence is missing.
The strength of evidence is addressed as it relates to relevancy and sufficiency.	One aspect of strength of evidence is addressed (relevancy or sufficiency).	The strength of the evidence is weakly addressed (mentioned, but not explained).	The strength of the evidence is not addressed.
Scientific reasoning explicitly uses an identified crosscutting concept as a central frame for explanation.	Scientific reasoning explicitly uses an identified crosscutting concept.	An appropriate crosscutting concept is identified in the explanation.	An appropriate crosscutting concept is not identified in the explanation.
The scientific reasoning is accurate, linking the evidence to the foundational ideas in the science discipline(s).	The scientific reasoning is accurate, weakly linking evidence to the foundational ideas in the science discipline(s).	The scientific reasoning has minor errors.	The scientific reasoning has major errors or is missing.

Note: Rubric for Written Scientific Argument from NGSS Rollout #3. CA NGSS Collaborative, 2016. Adapted with permission.

Next Generation Science Standards (NGSS)

This lesson is building toward:

PERFORMANCE EXPECTATIONS (PE)	
MS-PS2-3	Ask questions about data to determine the factors that affect the strength of electric and magnetic forces. [Clarification Statement: Examples of devices that use electric and magnetic forces could include electromagnets, electric motors, or generators. Examples of data could include the effect of the number of turns of wire on the strength of an electromagnet, or the effect of increasing the number or strength of magnets on the speed of an electric motor.] [Assessment Boundary: Assessment about questions that require quantitative answers is limited to proportional reasoning and algebraic thinking.]

NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

SCIENCE AND ENGINEERING PRACTICES (SEP)
Planning and Carrying Out Investigations
• Plan an investigation ~~individually and~~ collaboratively, and in the design: identify independent and dependent variables and controls, ~~what tools are needed to do the gathering~~, how measurements will be recorded, ~~and how many data are needed to support a claim.~~
Constructing Explanations and Designing Solutions
• Apply scientific reasoning to show why the ~~data or~~ evidence is adequate for the explanation ~~or conclusion.~~
Obtaining, Evaluating, and Communicating Information
• Critically read scientific texts adapted for classroom use to determine the central ideas and/or obtain scientific and/or technical information to describe patterns in and/or evidence about the natural and designed world(s).
Engaging in Argument from Evidence
• Compare and critique two arguments on the same topic and analyze whether they emphasize similar or different evidence and/or interpretations of facts. • Respectfully provide and receive critiques about one's explanations, procedures, models and questions by citing relevant evidence and posing and responding to questions that elicit pertinent elaboration and detail. • Construct, use, and/or present an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem.

Appendix 8.5

DISCIPLINARY CORE IDEAS (DCI)
PS2.B: Types of Interactions
• Electric and magnetic (electromagnetic) forces can be attractive or repulsive, and their sizes depend on the magnitudes of the ~~charges~~, currents, or magnetic strengths involved and on the distances between the interacting objects.

CROSSCUTTING CONCEPTS (CCC)
Cause and Effect
• Cause and effect relationships may be used to predict phenomena in natural ~~or designed~~ systems.
Structure and Function
• Analyze many complex natural ~~and designed~~ structures and systems to determine how they function.
Patterns
• Patterns can be used to identify cause and effect relationships. • Graphs, charts, and images can be used to identify patterns in data.

Common Core State Standards (CCSS)

CCSS ELA SPEAKING & LISTENING
CCSS.ELA-LITERACY.SL.8.1
Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 8 topics, texts, and issues, building on others' ideas and expressing their own clearly.
CCSS.ELA-LITERACY.SL.8.4
Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation.
CCSS ELA WRITING
CCSS.ELA-LITERACY.WHST.6-8.2
Write informative/explanatory texts, including the narration of ~~historical events~~, scientific procedures/experiments, or technical processes.
CCSS MATH EXPRESSIONS & EQUATIONS
CCSS.MATH.CONTENT.7.EE.B.4
Use variables to represent quantities in a real-world or mathematical problem, and construct simple equations and inequalities to solve problems by reasoning about the quantities.

Appendix 8.5

California English Language Development (ELD) Standards

CA ELD		
Part 1.8.11 Justifying own arguments and evaluating others' arguments in writing		
EMERGING	**EXPANDING**	**BRIDGING**
P1.8.11 a) Justify opinions by providing some textual evidence or relevant background knowledge with substantial support. b) Express attitude and opinions or temper statements with familiar modal expressions (e.g., *can, may*).	**P1.8.11** a) Justify opinions or persuade others by providing relevant textual evidence or relevant background knowledge with moderate support. b) Express attitude and opinions or temper statements with a variety of familiar modal expressions (e.g., *possibly/likely, could/would*).	**P1.8.11** a) Justify opinions or persuade others by providing detailed and relevant textual evidence or relevant background knowledge with light support. b) Express attitude and opinions or temper statements with nuanced modal expressions (e.g., *potentially/ certainly/absolutely, should/might*).
In addition to the standard above, you may find that you touch on the following standards in this lesson as well: 1.8.1: Exchanging information and ideas with others through oral collaborative discussions on a range of social and academic topics 1.8.2: Interacting with others in written English in various communicative forms (print, communicative technology and multimedia) 1.8.3: Offering and justifying opinions, negotiating with and persuading others in communicative exchanges 1.8.5: Listening actively to spoken English in a range of social and academic contexts 1.8.6: Reading closely literary and informational texts and viewing multimedia to determine how meaning is conveyed explicitly and implicitly through language 1.8.8: Analyzing how writers and speakers use vocabulary and other language resources for specific purposes (to explain, persuade, entertain, etc.) depending on modality, text type, purpose, audience, topic, and content area 1.8.12: Selecting and applying varied and precise vocabulary and other language resources to effectively convey ideas 2.8.5: Modifying to add details 2.8.6: Connecting ideas		