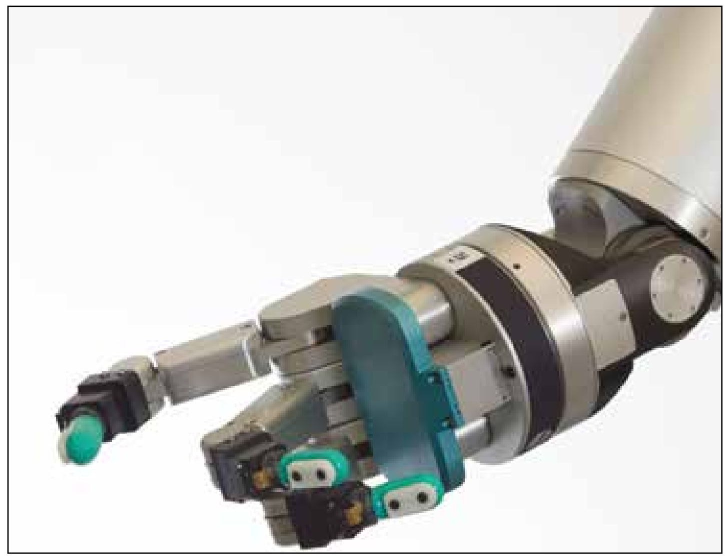
Science News
IN HIGH SCHOOLS | EDUCATOR GUIDE



FROM LEFT: GIL MENDA, HOY LAB AT CORNELL; PHOTO: JOANNE LEUNG, UCLA ENGINEERING, PRODUCTS FROM SYNTOUCH, LLC AND BARRETT TECHNOLOGY INC.

November 12, 2016

Spider Hearing and Robot Senses

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SN EDUCATOR GUIDE

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About this Issue

This educator guide focuses on how animals and robots sense and respond to the world around them. The article "Jumping spider hears distant sounds" explores how organisms can sense sound, even if they don't have eardrums. After observing certain arachnids under various conditions and recording neuron activity, researchers report that the spiders hear a specific range of airborne sound wave frequencies from at least three meters away. Like spiders and other animals, learning robots will also have to qualitatively observe the world around them and make meaning from sensory inputs. The article "Robot awakening" explores technological advances in robot sensing. The guide touches on the physics of sound, the physiology of hearing and the relationships between animals and their prey. Students can focus on a particular phenomenon of interest or examine the cross-curricular intersections that emerge from animal behavior studies. Along with a main focus on the qualitative observations of animals, this guide also includes a short section focused on how robots are being programmed to collect sensory data to effectively interact with the world around them.

Connections to Curricula

- Qualitative observations
- Predator-prey relationships
- Sound waves and vibration
- Biomimicry
- Animal behavior
- Physiology of sound perception
- Experimental design
- Coding

What's in this Guide?

- **Article-Based Observation**: These questions focus on reading and content comprehension by drawing on information found in the article "Jumping spider hears distant sounds." Questions focus on animal behavior and the nature of experimental design and modification.
- **Quest Through the Archives**: With Internet access and your school's digital access to *Science News*, your students can use this short section to explore the history of robotics as reported by *Science News* since 1922. This quest is based on the article "Robot awakening."
- **Cross-Curricular Discussion**: The majority of these questions and extension prompts connect to the article "Jumping spider hears distant sounds" and encourage students to think about how animals sense the world, as well as the nature of sound as a wave. There are many different links to additional information, simulations and other teaching tools. Engineering and experimental design concepts are embedded in the extension prompts, and the section is subdivided roughly by subdiscipline for educators who would like to focus on one particular topic area. The extension prompts are either more topic specific or more conceptually advanced. Following the questions related to the spider article, there is a section about the article "Robot awakening" that focuses on the importance of robots being able to process sensory data. Prompts encourage students to think about how they might design a

robot to complete a task, and how they might incorporate biomimicry into their robot design. Students can also explore coding at their own pace.

- **Activities:** The activities explore how animals sense and respond to their world. In "What is this animal telling me" students use their observational skills to practice cataloging and analyzing animal behavior. This is followed by "You are the animal biologist," which asks students to design their own experiments based on an animal of their choosing.

Standards Alignment

Next Generation Science	Common Core
Waves and their Applications in Technologies for Information Transfer: HS-PS4-1, HS-PS4-3	ELA Standards: Reading Informational Text (RI): 1, 2, 7
From Molecules to Organisms: Structures and Processes: HS-LS1-2	ELA Standards: Writing (W): 2, 3, 6, 9
Ecosystems: Interactions, Energy and Dynamics: HS-LS2-2, HS-LS2-7, HS-LS2-8	ELA Standards: Speaking and Listening (SL): 1, 6
Earth and Human Activity: HS-ESS3-6	ELA Standards: Reading for Literacy in Science and Technical Subjects (RST): 1, 2, 4, 8, 9
Engineering Design: HS-ETS1-3	ELA Standards: Writing Literacy in History/Social Studies and Science and Technical Subjects (WHST): 2, 4, 6, 7, 9

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Article-Based Observation

Directions: After reading the article "Jumping spider hears distant sounds," answer these questions:

1. If spiders don't have eardrums, which part of their body do they use to hear, according to scientists? What physically happens to this part of their body that triggers a response? Are there other animals that may hear similarly?

2. How did the scientists determine if a spider heard a noise disturbance? Define both the qualitative and quantitative data that the scientists collected to determine when a spider heard a disturbance. Is this data representing the independent or dependent variable in the experiments?

3. What hypothesis was disproved when the researchers tested their ideas on a table protected from vibrations? State the original hypothesis and the new conclusion.

4. Explain why the vibration-protected table was necessary to the experiment. Is sound wave frequency the independent or dependent variable in these table experiments?

5. To share this great discovery with your friends, you post a picture like the one in the article on Instagram. Describe the picture you would post and write the caption you would include to help your friends understand what you learned.

6. Many news sources, including NPR and the *Washington Post*, reported this finding on jumping spiders. Find additional stories and compare and contrast each outlet's approach.

Responses to Article-Based Observation

1. If spiders don't have eardrums, which part of their body do they use to hear, according to scientists? What physically happens to this part of their body that triggers a response? Are there other animals that may hear similarly?
   Possible student response: *Scientists have found that these jumping spiders, without eardrums, probably hear with their tiny leg hairs. When a disturbance moves these hairs, a spider responds. Jérôme Casas has observed that the hairs on cricket legs appear to respond to airplanes flying overhead.*

2. How did the scientists determine if a spider heard a noise disturbance? Define both the qualitative and quantitative data that the scientists collected to determine when a spider heard a disturbance. Is this data representing the independent or dependent variable in the experiments?
   Possible student response: *Bursts of nerve cell/neuron activity were recorded from probes in a spider's brain and researchers also observed the physical movement of hunkering down motionless. Both data indicated to scientists that spiders heard a disturbance. This data measures the dependent variable.*

3. What hypothesis was disproved when the researchers tested their ideas on a table protected from vibrations? State the original hypothesis and the new conclusion.
   Possible student response: *Scientist thought that spiders could hear airborne sounds only at very short distances. The researchers determined that spiders can also hear airborne sound waves from 70 to 200 hertz from distances of several meters.*

4. Explain why the vibration-protected table was necessary to the experiment. Is sound wave frequency the independent or dependent variable in these table experiments?
   Possible student response: *Since sound waves can cause objects to vibrate, the researchers had to eliminate the vibrations traveling through objects in order to determine whether spiders could actually perceive sound waves traveling through air. Vibration of the surface on which the spider stood was a confounding variable that needed to be eliminated. Sound wave frequency is the independent variable in the experiments.*

5. To share this great discovery with your friends, you post a picture like the one in the article on Instagram. Describe the picture you would post and write the caption you would include to help your friends understand what you learned.
   Possible student response: *I would post a picture of the spider zoomed in on its leg hair with the caption: Spiders use their leg hairs to hear sound waves across great distances!*

6. Many news sources, including NPR and the *Washington Post*, reported this finding on jumping spiders. Find additional stories and compare and contrast each outlet's approach.
   Possible student response: *All three sources cover the same core facts, however, each treats the story slightly differently. The* Washington Post *adds a nod to Spiderman and includes some humor, while NPR focuses more on quotes from the researchers and their study.* Science News *gets into the details of the study and better summarizes the big ideas.*

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Quest Through the Archives

1. Search for an article discussing a prediction about robotics that has not happened yet. Explain the prediction.

2. What is the earliest *Science News* article you can find that reports on programming a robot? How does this article compare with the programming developments and challenges described in the article "Robot awakening"?

3. Find another article describing an example of biomimicry. What property or function of the organism was mimicked? What design inspiration was created?

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Responses to Quest Through the Archives

1. Search for an article discussing a prediction about robots that has not happened yet. Explain the prediction.
   Possible student response: *Even though the Sputnik mission was the beginning of the robotic satellite era, it didn't launch human colonization of the moon or other planets, as many sources had predicted.*
   www.sciencenews.org/article/sputnik-50

2. What is the earliest *Science News* article you can find that reports on programming a robot? How does this article compare with the programming developments and challenges described in the article "Robot awakening"?
   Possible student response: *In 1937, a robot solves nine linear algebraic equations simultaneously. A set of tilting plates and a mechanical mechanism allow for the quick manipulation of variables.*
   www.sciencenews.org/sites/default/files/calculator.pdf

3. Find another article describing an example of biomimicry. What property or function of the organism was mimicked? What design inspiration was created?
   Possible student response: *"Chemistry au naturel" highlights how efficient cellular reactions have inspired unique methods for laboratory molecular synthesis.*
   www.sciencenews.org/article/chemistry-au-naturel

Cross-Curricular Discussion

After students have had a chance to review the article "Jumping spider hears distant sounds," lead a classroom discussion based on the questions that follow. General questions outlined in Blackline Master 3 can be handed out to students before your discussion to help them prepare. If you don't want to use all the questions, you can circle or state those specific questions you want your students to focus on.

Before starting the discussion, have students watch the video of the jumping spider that is embedded in the online version of the article. The video shows a spider reacting to sound wave stimuli.

BIOLOGICAL SCIENCES

Discussion Questions:

1a. Ask students how many animals they can think of that don't have ears similar to human ears. Students might brainstorm or research a list of animals and then identify whether or not they have these kind of ears. This article sheds light on the concept that one doesn't need ears like human ears to sense sound or interpret sound vibrations. How else do animals sense sound? At the same time, you can ask your students: Do all animals need to sense airborne sound? Why or why not? What other ways do animals take in qualitative information to understand the world around them? Students can use the chart provided in Blackline Master 3 to help them organize their thoughts.

1b. The article mentions that wasps prey on jumping spiders. Ask students why they think these spiders need to be able to perceive very low frequency sounds? Why might this ability have evolved over time? [*Being able to hear the wing sounds of fast-flying predatory wasps could increase a spider's chances of survival.*]

1c. Humans and spiders hear best at different frequency ranges. Ask students to find these ranges as stated in the article [*Spiders: 70–200 hertz. People: 500–1,000 hertz*]. Ask students what they know about how we hear sound. Students may have studied this in elementary or middle school. Can they name the parts of the body involved in sensing and processing sound? [*Sound waves enter the ear canal. When they reach the eardrum, the vibrations move the middle ear bones (ossicles). The movement of the bones moves fluid, which moves the tiny hair cells in the cochlea. The vibrations are changed into electrical signals that are sent to the brain.*]

Extension Prompts:

1d. Ask students to select a specific animal they'd like to learn more about. Ask how this animal sees, tastes, smells and touches (or doesn't)? Have students think about what makes their animal well-suited to survive in its environment.

1e. Ask students what they can hear? Start with a site like Noise Addicts Hearing Test to determine the range of frequencies they can hear. Ask students to do research to determine if their frequency range is considered normal for someone their age. Can the ability to hear a wide range of frequencies decline over time? Why is it important for humans to hear? Do humans need hearing to communicate? This question can lead to a discussion about coping with hearing loss or lack of any hearing ability. Students might want to brainstorm ways they can protect their hearing.

PHYSICAL SCIENCES

Discussion Questions:

2a. Ask students to brainstorm different types of waves [*ocean waves, X-rays, ultraviolet waves, microwaves, sound waves, radio waves, visible light waves, earthquake waves, waves of the hand*]. Have students define the different types of waves. Penn State's site on Longitudinal and Transverse Wave Motion has animations for students to explore. Have students sort their examples of waves into the correct types. How would they characterize a sound wave? Tell students the parts of a wave (as described at this link from www.schoolphysics.org) and have them use this vocabulary to describe waves on the electromagnetic spectrum. [*Sound is a mechanical wave because air particles move as the energy of the sound wave passes through. Sound is a longitudinal wave because the direction that air particles move is parallel to the direction of wave propagation. Sound can also be described as a pressure wave because the pressure of the air increases and decreases as the sound wave moves.*] How are sound waves similar to or different from other kinds of waves?

2b. The "Jumping spider hears distant sounds" article says that scientists have long known that spiders can sense the vibrations of the surfaces on which they are standing. Ask students to describe a time when they felt sound more than heard it. [*Students might refer to a time when they stood close to a speaker at a concert and felt the base, or when they felt the vibration of their own voice by placing a hand on their neck.*]

Extension Prompts:

2c. There are many ways to model longitudinal and transverse waves using a piece of string and a Slinky. If your students haven't studied wave characteristics before, you might want to take some time to demonstrate these wave characteristics. Students can also manipulate waves using animations, like these PhET simulations from the University of Colorado Boulder, to compare and contrast the characteristics of sound and electromagnetic waves, for example.

2d. Ask students what they know about how sound waves are measured. What units of measurement are used? [*Hertz, decibels, meters/second.*] Students can research what each unit of measure is used for and some examples of the unit's use. [*Hertz (Hz) measures the frequency of sound, the number of pressure oscillations that occur per second. Decibels describe the loudness of the sound on a logarithmic scale. The speed of sound (meters/second) describes how fast the sound wave travels, which is dependent upon the medium it travels through.*]

2e. Students can explore sound waves and the relationship between sound and vibration through a number of simple demonstrations, including this one available from the Acoustical Society of America, which helps students explore sound using a tuning fork. Ask students to consider what they think would happen to a sound wave under different conditions (use prompts given on Black Master 3). Then have them brainstorm how they could revise the demonstrations to test their own ideas.

2f. Based on what students know about the science of sound, ask them why music is sometimes described as something that is felt rather than heard. Discuss the types of music or specific instruments that resonate most with students and what it means when they "feel the music." Have students examine an instrument and explain how its sound is made.

ENGINEERING AND EXPERIMENTAL DESIGN

Extension Prompts:

3a. After students watch the video embedded in the version of the article that appears online, have them explain the experiment that they are seeing. Have them identify the hypothesis tested and the experimental variables. Have them explain experimental modifications that were made. Ask them to design another experiment for testing the jumping spiders' sense of sound.

3b. After discussing types of musical instruments, students can take the idea further by exploring instruments that people including Gunnar Schonbeck and Philip Glass have created on their own. Or, students can design their own musical instruments.

QUALITATIVE OBSERVATION AND ROBOTS

These questions and prompts will explore qualitative observation through the article "Robot awakening."

Discussion Questions:

4a. Ask students what "artificial intelligence" means to them? As robots become better at everyday tasks, are there things that a robot should not be allowed to do? Are there ethical lines that should not be crossed?

4b. According to the article, why is it important for robots to be able to sense their environment? What are some different methods scientists in the article are using to build robots that can make decisions based on the qualitative data they collect (their senses)?

4c. What are some ways that robots are being used in your community? What services do they provide and how are they an asset? Are there downsides to having robots perform these tasks?

4d. Scientists and engineers are looking to nature to find inspiration to solve problems. Explain the concept of biomimicry to your students. What are some examples cited in the article? [*The gecko-inspired "stickybot" that climbs walls, for example.*] Ask students if they can think of other examples.

Extension Prompts:

4e. Ask students to brainstorm some tasks that they wish a robot could do for them, like finishing their homework. Have them sketch their own design for such a robot and encourage them to borrow ideas from nature to help the robot perform a task. Have students share their designs with each other and compare those that would accomplish similar tasks. How might students determine which design is best?

4f. The “Robot awakening” article talks about the challenge of robots needing to prioritize incoming sensory information from their environment. Have students work in pairs or small teams to write a set of directions for the robot to follow so it can prioritize information and know what information requires a response or attention. If your students are experienced with a coding language, have them use it to design directions for a robot. If your students are less experienced with coding, consider having them write out the instructions as a series of logic statements. Have groups share their instructions and look for ways to make them even better. Students who want to learn more about coding can explore Hour of Code, where there are a variety of coding experiences across levels and interest areas.

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Cross-Curricular Discussion

Directions: The following list of discussion questions is provided to help you take notes, brainstorm ideas and test your thinking in order to be more actively engaged in class discussions related to the articles.

BIOLOGICAL SCIENCES

1a. List as many animals as you can think of that don't have ears like human ears.
What are some ways that animals without ears like human ears sense sound and other vibrations?
Make a chart of the senses and list how different animals accomplish this sensory task. Identify as many ways of sensing as you can.

Sense	**Animal**	**How the animal accomplishes the task**
Hearing (perceiving sound)		
Sight		
Touch		
Taste		
Smell		

1b. Why might it be helpful for spiders to perceive low frequency sounds? Why might this ability have been selected for over time?

1c. What frequency ranges can humans hear best and what frequency ranges can spiders hear best, as stated in the article?
How do humans hear sound? What do you know about the biology of the human ear? Research and name the parts of the body involved in human hearing and processing sound?

1d. Select a specific animal you would like to learn more about. Do research to determine how this animal sees, tastes, smells and touches (or doesn't). In what ways is this animal well-suited to its environment?

1e. Explore the site Noise Addicts Hearing Test (www.noiseaddicts.com/2009/03/can-you-hear-this-hearing-test) to determine the range of frequencies you can hear best. Do research to determine if this frequency range is normal for your age.
Why is hearing important for humans?
Can your ability to hear a wide range of frequencies decline? Research and explain. How can you protect your ability to hear the frequencies you can hear today?

PHYSICAL SCIENCES
2a. List as many examples of waves as you can.
How would you describe a sound wave? How is it different from and similar to other waves (ocean waves, light waves, etc.)?
Explore different types of waves and their characteristics by visiting Penn State's site on Longitudinal and Transverse Wave Motion (www.acs.psu.edu/drussell/demos/waves/wavemotion.html).
Which waves that you listed above are longitudinal, transverse and surface waves?
Draw a representation of both a transverse and longitudinal wave and label their parts.

2b. Think of a time when you thought you could feel sound, not just hear it. Describe where you were and what you were doing. What does it mean to say you were "feeling" sound? How did you know you were sensing sound?
What does it mean to "feel the music"? How would you feel the vibrations that your voice makes when you speak or sing?

2c. Using the resources provided by your teacher, explore the similarities and differences of sound waves and electromagnetic radiation waves.

2d. How are sound waves measured? What units of measurement are used? List some examples of when you would use each unit of measure.

2e. What do you think would happen to a sound wave as it travels…

- from air to under water?
- through a solid versus a liquid versus a gas?
- on a hot versus a cold day?

How could you test out your ideas about how a sound wave moves through different media and conditions?

2f. Deconstruct a musical instrument from a scientific perspective. How is sound produced by the instrument? Identify the sound frequency range of the instrument.

ENGINEERING AND EXPERIMENTAL DESIGN

3a. Explain the experiment that the researchers in the article "Jumping spider hears distant sounds" performed. State their hypothesis and experimental variables. What were some of the challenges they faced? Design your own experiment to test spider hearing. What question would you ask? How would you set up the experiment? What would the variables be? How would you minimize experimental error?

3b. Explore instruments that people including Gunnar Schonbeck and Philip Glass have created on their own. Use these instruments as inspiration to design your own musical instrument. Be ready to explain your design to your classmates.

QUALITATIVE OBSERVATION AND ROBOTS

4a. What is "artificial intelligence"? Give one example from the article and one from your experience. Are there certain tasks that should not be performed by robots? Are there ethical lines that need to be considered?

4b. According to the article, why is it important for robots to be able to sense their environments? What are some different methods scientists in the article are using to build robots that can make decisions based on the qualitative data they collect (their senses)?

4c. What are some ways that robots are being used in your community? What services do they provide and how are they an asset? Are there downsides to having robots perform these tasks?

4d. Explain how scientists and engineers are looking to nature to find inspiration to solve problems. Define biomimicry and give examples of biomimicry that were mentioned in the article.

4e. What are some tasks that you'd like a robot to be able to do for you? Pick a task and design an idea for how a robot could be built and programmed to perform the task. Try to incorporate biomimicry into your design. Sketch your design and be prepared to share it with your classmates.

4f. "Robot awakening" discusses the challenge of robots needing to prioritize incoming sensory information from their environment. With a partner, write a set of directions for the robot to follow so it can prioritize information and know what information requires a response or attention.

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Activities

ACTIVITY 1: WHAT IS THIS ANIMAL TELLING ME?

Class time: Approximately 30 to 60 minutes

Purpose: Practice observing animal behavior

Notes to the teacher: This activity begins by using dogs as an example but can be completed using any animal that is available and familiar to students.

Materials:

- Internet access or a printout of a dog behavior chart (for example, this "Dog to English translation chart" from Dogs for Defense or this Canid Ethogram from Texas A&M University)
- Internet access to *Science News for Students* or a printout of the article "Fair play" found at www.sciencenewsforstudents.org/article/fair-play
- Video of dog behavior (there are numerous available on YouTube or create your own)

Directions:

1. Ask students to think about how animals, including insects and spiders, can't use words to communicate. And yet we can know something about their state by observing specific behaviors.

2. Ask students what they might be able to learn from an animal based on observations of that animal's behavior (accept all reasonable answers). Discuss how animals, including bees, communicate with each other as well as with predators and prey. In 1973, Karl von Frisch shared the Nobel Prize in physiology or medicine for his work in understanding how honeybees communicate. Students might be interested in researching his work and that of others who study animal communication.

3. Give students a guide to dog behavior and discuss. Then watch a video of dogs interacting with a human and use the guide to decipher what that human could infer from the dog's behavior.

   a. Discuss students' findings. What was easy or difficult to decipher? Did everyone see the same behaviors and interpret them in the same way? What would reduce variability in observations and/or interpretations?

   b. This could lead to a discussion on why scientists often record videos of animal behavior and how those videos are used for analysis. Such a discussion could also bring up questions of whether video can distort the animal's original behavior by reducing the visual field, for example.

4. Extension: Have students read, "Fair play" and discuss the following questions:

   a. What do dogs learn from playing?

   b. Why are videos used by scientists to better understand dog play? How does new technology help scientists do this kind of study?

c. How does play help animals and people explore the limits of socially appropriate behavior?

d. What aspects of the environment could affect play?

ACTIVITY 2: YOU ARE THE ANIMAL BIOLOGIST

Class time: Approximately two, 60-minute class sessions plus possible time outside of class

Optional Materials:

- A motion-activated camera such as this one available on ebay for around $15

Directions:

1. Students should work in pairs to develop a behavioral study. Educators should define the type of study and approach based on what is most appropriate for their classroom. Consider whether students should choose a pet at home or an insect in the classroom to observe. Decide what parameters you should place on the nature or scope of their research. (Possible animals to consider include ants, bean beetles, fruit flies, pill bugs, etc.)

2. Have students select a stimulus (making a loud sound, knocking on a closed door, turning on a light, for example). They will present the stimulus to the animal to study how the animal responds. Make sure the chosen stimulus will not physically harm the animal.

3. Students will plan their experiment with the help of Blackline Master 4. Ask them questions to guide their design process:

   a. What is your hypothesis?

   b. What are your variables?

   c. How will you administer the stimuli?

   d. How many individual animals will you test? All of the same species? Same sex?

   e. How will you perform your test?

   f. How will you collect your and record your data?

   g. How will you be sure you, as the researcher, aren't influencing the animal's behavior?

4. Give students time to collect their data and bring it back to class. Have students share their data and discuss the most appropriate type of statistical analysis. This could be very simple (mean, median, mode) or could be more robust (ANOVA, T-test) based on students' math backgrounds. What questions come from looking at the data? How might these questions be answered if the study was continued?

5. Scientists share their findings. Some scientists write scholarly papers. Others speak about their findings at community meetings or participate in the creation of public service announcements. Ask groups to determine the best way to communicate their findings to an interested audience.

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Activity: You are the Animal Biologist

Part 1 Directions: Use the prompts below to help you plan and execute your experiment.

1. What animal do you want to observe?
2. Define the stimulus you will use for your test.
3. Develop a hypothesis based on what you are trying to determine.
4. Define your experimental variables. Are there any potential confounding variables that you should design your experiment to avoid?
5. How will you administer the stimuli?
6. What data will you collect? How will you organize it? Create a data table to organize your data collection.
7. What statistical test are you planning to use based on the data you hope to collect?
8. How many different animals do you plan to observe? Does the statistical test you are hoping to use require a certain number of samples?
9. Write your procedure for performing your experiment. Be as detailed and specific as possible.

Part 2 Directions: Now, use the prompts below to analyze your data.

1. Based on your chosen statistical test, what story does your data tell about your animal's behavior? Explain.

2. Did you prove or disprove your hypothesis?

3. Decide on a way to visually display your data and results? Make sure you label your visual and provide keys for any necessary information.

4. What sources of error do you believe existed in your experiment? Would there be a way to remove the potential error in a future experiment? Explain.

5. As you examine your data, what new questions arise? How could you test those new questions?