December 10, 2016
Animal Math

SOCIETY FOR
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About this Issue

"Animal math" introduces students to studies exploring whether any animals other than humans have a number sense. Certain other animals seem to be able to distinguish a difference in quantity, but are these animals recognizing discrete quantities or determining, for example, the greatest overall treat volume? Scientists are still debating many such questions. Designing nonverbal experiments that minimize confounding variables is part of the challenge. Scientists would also like to know how animals' quantitative abilities evolved. Like the scientists, students can focus on distinguishing between discrete quantities and continuous qualities or examine the cross-curricular intersections that bring neuroscience, animal behavior and experimental design together. This guide invites students to plan their own experiment to judge the strength of their peers' number sense, regardless of their comfort with high-level calculations.

Connections to Curricula

Sense of quantities

Discrete vs. continuous qualities

Animal behavior

Common ancestry

Inheritable traits

Isolating variables

Nerve function

What's in this Guide?

■ Article-Based Observation: These questions focus on reading and content comprehension by drawing on information found in the article "Animal math." Questions focus on the quantitative concepts covered in the article and the challenges of experimental design.

■ 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 human evolution and how people in different professions and different parts of the world use and manipulate numbers, as reported by *Science News*.

■ Cross-Curricular Discussion: These questions and extension prompts encourage students to think about the complexity of experimental design. Students can explore confounding variables and how these variables may hinder scientists' ability to understand how animals sense numbers. The section highlights decisions scientists make when designing an experiment, such as the necessary sample size, and includes a graphical analysis about neuron activity. The section is subdivided for educators who would like to focus on one particular topic area. The extension prompts are either more topic-specific or more conceptually advanced.

■ Activity: The activity "How good is your number sense?" guides students through the process of designing their own experiment to study their peers' sense of discrete quantities. After an initial experimental idea demonstrated by the teacher, students are led through the design process, which focuses on minimizing confounding variables and selecting a sample size. Statistical analyses may be explored.

Standards Alignment

Next Generation Science	Common Core
From Molecules to Organisms: Structures and Processes: HS-LS1-2	ELA Standards: Reading Informational Text (RI): 1, 2, 4, 6,
Ecosystems: Interactions, Energy, and Dynamics: HS-LS2-8	ELA Standards: Writing (W): 2
Biological Evolution: Unity and Diversity: HS-LS4-4	ELA Standards: Speaking and Listening (SL): 1, 2, 4, 6
	ELA Standards: Reading for Literacy in Science and Technical Subjects (RST): 1, 2, 3, 4, 5, 6, 8, 9
	ELA Standards: Writing Literacy in History/Social Studies and Science and Technical Subjects (WHST): 2, 4, 7, 9

December 10, 2016
Animal Math

Article-Based Observation

Directions: After reading the article "Animal math," answer these questions:

1. How does the author use interesting or unexpected language to engage the reader? What are a few examples?

2. "Animal math" summarizes many experiments attempting to determine if animals have a number sense — what question is posed about the evolution of this sense?

3. Define the term "numerosity." Is it defined as a discrete or continuous quality? Explain with examples.

4. How do discrete versus continuous qualities cause experimental uncertainty for researchers trying to analyze animal "numerosity"? Find an example of a specific experiment.

5. What is subitizing? What is Weber's law, mentioned on Page 23? Compare and contrast the two.

6. You work at a pet store and want to use the scientific findings mentioned in the article to come up with a creative way to boost sales. Select one or more animals from the article and create the text for an e-mail blast that would be sent out to prospective customers. Be careful not to make assumptions about the information given in the article.

Responses to Article-Based Observation

1. **How does the author use interesting or unexpected language to engage the reader? What are a few examples?** Possible student response: The author uses language to create a heightened sense of competition ("fish versus humans face-offs") and establish a relationship ("fish and people share some idiosyncrasies"). The author uses "barnyard" and "zoo" to convey the scope of animals scientists are studying.

2. **"Animal math" summarizes many experiments attempting to determine if animals have a number sense — what question is posed about the evolution of this sense?** Possible student response: Scientists want to determine if the animals' quantitative abilities have a shared ancestry or if those abilities arose independently in different animals.

3. **Define the term "numerosity." Is it defined as a discrete or continuous quality? Explain with examples.** Possible student response: "Numerosity" is a term scientists use to describe a number of items recognized nonverbally. If dogs were able to identify the specific quantity of treats in a bowl, they would be identifying a numerosity that changes in separate, specific units. Surface area or volume of treats are considered continuous qualities because they can vary over an infinite range of units.

4. **How do discrete versus continuous qualities cause experimental uncertainty for researchers trying to analyze animal "numerosity"? Find an example of a specific experiment.** Possible student response: Some quantitative judgments do not require numerosity. The experiment performed by Clive Wynne and Maria Elena Miletto Petrazzini at a doggie daycare tested whether dogs chose a bowl with a few large pieces of treats or a bowl of many smaller pieces but a lower total amount. Not surprisingly, the dogs chose the bowl with more food. The dogs chose based on a continuous quality, but the researchers can't tell from this experiment whether the dogs recognize numerosity.

5. **What is subitizing? What is Weber's law, mentioned on Page 23? Compare and contrast the two.** Possible student response: Subitizing is the idea that humans can see and know the number of a small group of items without counting. Weber's law says that distinguishing a relationship between two quantities (e.g., which group contains a greater number of items) is easier when the quantities are very different or when the quantities are smaller. Both are phenomena observed by scientists studying sense of numbers. Subitizing works with single quantities, while Weber's law applies to comparisons.

6. **You work at a pet store and want to use the scientific findings mentioned in the article to come up with a creative way to boost sales. Select one or more animals from the article and create the text for an e-mail blast that would be sent out to prospective customers. Be careful not to make assumptions about the information given in the article.** Possible student response: The ad might have a cute image of a new chick and say: "Need a buddy? In some cases, I've imprinted on quantity of buddies!"

Quest Through the Archives

Directions: After reading the article "Animal math," use the archives at www.sciencenews.org to answer these questions:

1. Find an example of another *Science News* article that discusses the evolution of a human characteristic. What is the topic of the article? Support your answer with a specific article.

2. Find another *Science News* article about how humans use or manipulate numbers. Have there been changes in this use over time?

3. Are there any people around the world who do not use or express numbers the same way you do? Find a related *Science News* article. Explain how this article relates to "Animal math."

December 10, 2016
Animal Math

Responses to Quest Through the Archives

1. **Find an example of another *Science News* articles that discusses the evolution of a human characteristic. What is the topic of the article? Support your answer with a specific article.** Possible student response: https://www.sciencenews.org/article/evolutions-ear. "Evolution's ear" suggests that genes related to hearing may have influenced the development of language.

2. **Find another *Science News* article about how humans use or manipulate numbers. Have there been changes in this use over time?** Possible student response: https://www.sciencenews.org/article/units-measure-are-getting-fundamental-upgrade. The article "Units of measure are getting a fundamental upgrade" summarizes the desire scientists have to define units of measurement based on absolute properties of nature, the fundamental constants, rather than based on a physical object.

3. **Are there people around the world who do not use or express numbers the same way you do? Find a related *Science News* article. Explain how this article relates to "Animal math."** Possible student response: https://www.sciencenews.org/article/pirah%C3%A3-challenge. The Amazonian tribe described in this article has a limited counting vocabulary. Scientists are exploring how this vocabulary affects the way these people live their lives. The scientists described in "Animal math" are trying to understand how the quantitative abilities of nonhuman animals affect the decisions they make.

Cross-Curricular Discussion

After students have had a chance to review the article "Animal math," lead a classroom discussion based on the questions that follow. You can copy and paste only the questions that apply to your discussion into a different document for your students.

BIOLOGICAL SCIENCES

Discussion Question:

1a. Ask students why abilities with quantities could be beneficial to a species? What might be the potential benefits of recognizing discrete numbers versus continuous qualities for animals? [*Recognizing continuous qualities could help animals identify which set of objects provides more food. They may not need to spend the time figuring out the discrete quantity of food pellets, for example. But recognizing discrete quantities may allow animals to know how many offspring they have so they can properly care for those offspring.*]

Do scientists agree that many animals have some kind of number sense?

Would having a numerical system be beneficial?

What are the benefits of recognizing discrete quantities?

What are the benefits of recognizing continuous qualities?

Extension Prompt:

2b. Scientists look for certain behaviors that may be useful in designing animal numerosity studies. The article mentions imprinting and hoarding. Ask students to define these terms and have them brainstorm examples. [*In art, "imprinting" is the act of making a mark on a surface, but in science "imprinting" is used to describe learning an attraction at a young age, such as to a parent. "Hoarding" refers to the storage of food beyond what an animal is going to eat immediately. When the food is hidden, it is sometimes called "caching."*] Ask why these behaviors might have an evolutionary benefit. [*Imprinting helps offspring stay near a parent, for protection and so they don't get lost. Hoarding helps save seasonal food for when food is less plentiful, for example.*] Can students think of situations in which these behaviors might be detrimental? [*Once a behavior is learned, it may be difficult to change it, even when circumstances or information changes.*]

What is "imprinting"? Can you name an example from the article?

What is "hoarding"? Can you name an example from the article?

What are some pros and cons of imprinting?

What are some pros and cons of hoarding?

PHYSICAL SCIENCES

Discussion Question:

2a. Have students examine the graph on Page 26 of "Animal math," also available as Blackline Master 3. Ask them to explain the experimental variables described by the graph. What is each axis measuring? [*The x-axis displays the number of dots or musical tones presented to the monkeys (1–4). The y-axis measures the normalized mean activity of four specific monkey nerve cells, represented as a percentage.*] Given the labeling of the y-axis, ask students what they think the term "normalized" means. [*To normalize data generally means to apply a mathematical function to it in order to have the data points fit within a specific range. In this study, it appears that neural activity of specific cells is normalized to a percentage from 0 to 100. However, there is no other information about the normalization process here.*] Students should try to analyze the graphical data displayed. Are there overall trends that they notice? Remind students to justify their stated trends with specific data. [*Generally, it appears that specific neurons in a monkey's brain respond to a specific numerical quantity — whether that quantity is presented as dots or sounds. For example, Cell 1 is the most responsive to the quantity one in terms of normalized mean activity. Specifically Cell 1 has approximately 100% normalized mean activity when one dot is observed and approximately 95% normalized mean activity when one sound is heard. The next highest mean response is Cell 2, which has approximately 30% normalized mean activity to one sound.*] Ask students about the implications of such a study. [*If scientists can under-stand how the brain recognizes information, they may be able to gain clues to high-level brain functions.*]

What variables are measured by the graph? Define the axes specifically.

What does "normalized" as in "normalized mean activity" mean?

Are there overall trends communicated by the graph?

Why is this type of study important for understanding animal behavior, including human behavior?

Extension Prompt:

2b. Depending on the level of your class, you may preface this discussion with this brief NBC Learn video describing how neurons work. Scientists suggest that measuring neural responses to stimuli could be use-ful in tracing the evolution of animals' quantitative abilities. Ask students what they know about how in-formation is transferred between nerve cells. They might want to draw a flow chart outlining the process of electrical and chemical activity. [*An electrical impulse specific to one neuron triggers a chemical release into the gap between neurons, called the synapse. The chemicals released, also called neurotransmitters, are received by a neighboring neuron which triggers a new electrical impulse on the second neuron. The process can continue to repeat.*] Relating back to the research mentioned in the article, how might scientists be able to measure the specific response of a neuron? [*Since neurons have electrical impulses, the cell voltage or cell potential may be measured with a type of voltmeter because it will change with a neural response.*]

How is information passed from one nerve cell to another?

What is the name of the location where nerve cells share information?

What part of the process is electrical and what part is chemical?

How might scientists be able to measure when a neural response occurs?

ENGINEERING AND EXPERIMENTAL DESIGN

Discussion Question:

3a. The article refers to a number of experiments, each done to gain evidence about whether nonhuman animals have their own quantitative abilities. Students can explore whether there is enough evidence to reach a conclusion. Students may help to develop specific concepts from the article to research further, based on their interests (suggested prompts are included below). Once the prompts are established, have students work in groups to prepare a presentation of evidence supporting and opposing a statement. Give them enough time to review the article and perform additional research.

Do scientists have enough evidence to conclude that…

The genes behind specific animal behaviors can be inherited.

Nonhuman animals' brains are hardwired for specific mathematical abilities.

What scientists learn about how an animal's brain processes quantity can help them understand how a human brain processes quantity?

Extension Prompt:

3b. Before scientists collect data from an experiment, they have to decide how many animals will be involved in their study. In this instance, the animals are a sample of a larger population. What is the difference between a sample size and the number of trials in an experiment? [*The sample size is the number of units from a population suggested for testing. A number of trials is how many times the experiment is run.*] How many samples are needed to test a hypothesis? [*You need at least a test sample and a control sample.*] What are the consequences of not having a large enough sample size? [*If your sample size doesn't represent the population, you will not get meaningful results.*] What are potential consequences of having too big a sample size? [*Trivial differences might appear to be statistically significant even though they aren't meaningful for any practical purposes. Also, a larger sample size requires more testing time and resources.*] Students can become familiar with how to use a sample size calculator, such as this one, and discuss levels of confidence. How does a scientist decide which units of a population to include in a study or experiment? [*Sometimes a simple random sample is OK, but sometimes samples need to be adjusted or stratified.*]

Define how a sample is different from a trial in an experiment.

What are the potential consequences of too small a sample size? What about too big a sample size?

What information is needed to determine a sample size needed for an experiment?

How does a scientist decide which units of a population to include in a study or experiment?

Cross-Curricular Discussion

Directions: Use this graph from "Animal math" to answer the related discussion questions assigned by your teacher.

Nerve response to dots or sounds
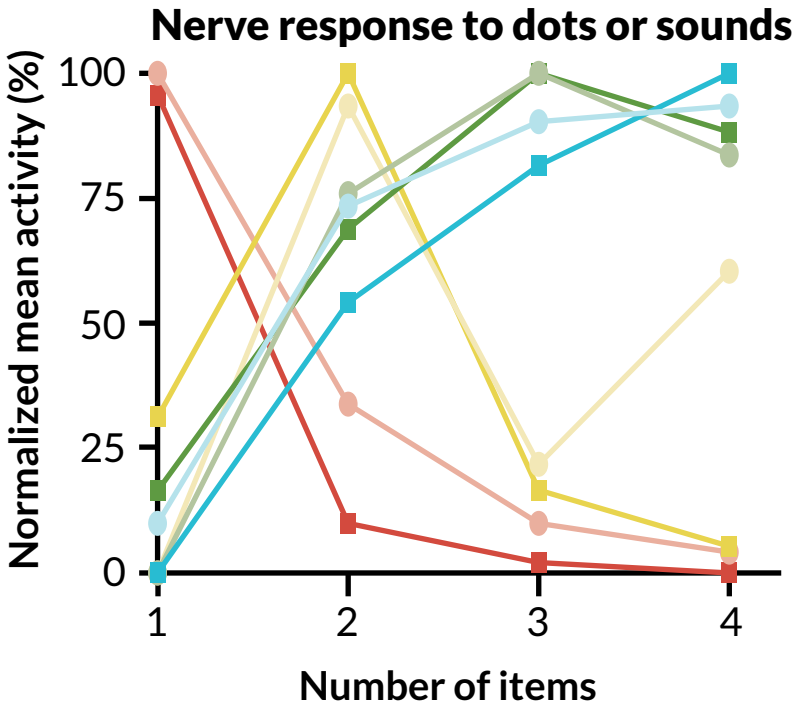
Legend:
- Cell 1 (sounds)
- Cell 1 (dots)
- Cell 2 (sounds)
- Cell 2 (dots)
- Cell 3 (sounds)
- Cell 3 (dots)
- Cell 4 (sounds)
- Cell 4 (dots)

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EDUCATOR GUIDE

December 10, 2016
Animal Math

Activity: How good is your number sense?

Class time: 2–3 class periods, depending on the depth of the experimental design and analysis

    Day 1: Teacher-led experimental activity and student experimental design

    Days 2–3: Experiment and analysis of data

Purpose: After an initial mini-experiment run by the teacher, students will divide up into groups. With Blackline Master 4 as a guide, they will design their own experiment to study the strength of students' sense of quantities. There will be a focus on isolating variables and selecting sample size.

Notes to the teacher: You may choose to have your students analyze their data with statistics or leave out statistical analysis. Rice University provides information on specific types of statistical analysis that might be useful for those with some background understanding of statistics.

Materials:

■ Access to the internet to use links provided

■ Paper and pencil or laptop for record keeping

■ Large-format paper (6 per group) and markers

■ Other objects for testing, as determined by students

Directions:

1. Tell students that you are going to give them a very simple experiment. Show a student the image of four squares. Remove this original figure and immediately show the same student the set of three options. Ask, "Which of the three choices is the same (surface area) as the original?" and tabulate the students' response (A, B or C). Allow only one second for a student to respond.
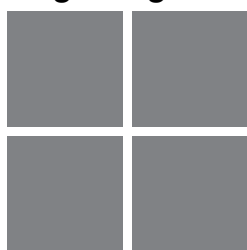
Original figure   **Students may choose A, B or C**
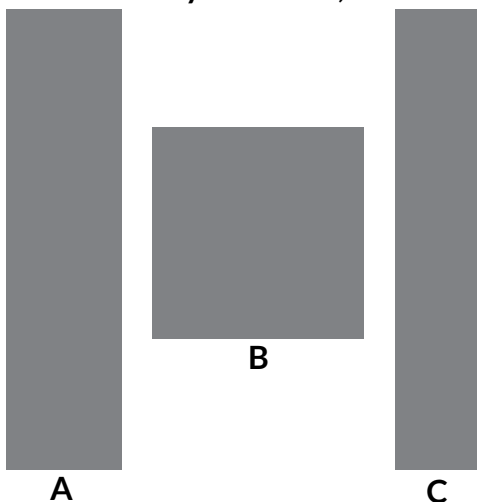
Repeat with at least 10 students and display the data:

Student	Selected "A"	Selected "B"	Selected "C"
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

2. Ask students to explain your experiment. What is it testing [*whether the subject can identify two equal surface areas*]? How was the test set up [*the subject examines one image, then looks at a series of choices and has to determine which has the same surface are*]? What are the strengths of the design? [*It is simple. The test is given to multiple test subjects. The response time is kept constant.*] What are some weaknesses of the design? Are there confounding variables? [*Each subject only looks at one set of images. It's unclear whether the right number of students in the class were tested in order to form any conclusions based on the results. Students being tested may be different ages, genders, etc.*] How many and which students were tested? Ask whether students think the same images in a different order would result in different responses from their subjects and why. Use this discussion to help students begin thinking about how they can design their own experiment. This experiment tests a continuous quality; have students design an experiment to instead study their peers' sense of numbers.

3. Have students form groups and select a possible question related to number sense that they would like to test. Students should refer to Page 23 for the example in the figure labeled "Reckoning with Weber's law." Would they like to compare the number sense of different categories of people (such as different age groups, math levels or genders)?

4. Give students time to create the visuals they will need to test the mathematical idea they selected. They'll need to decide on their experimental testing procedure. For example, how long will they give each subject to answer a particular question?

5. Have teams share their visuals and explain how each visual tests their specific variable. Other students should listen for any confounding variables, such as those described in the article. Based on this discussion, students may need to refine some of their visuals.

6. Teams need to plan the number of subjects that will be tested. For example, if there are 25 students in the class, should 10 be tested or is that too many/not enough? You can find various sample size calculators online, such as this one, but be sure students are aware of the challenges of statistical analysis.

7. Once a sample size is selected, how will students determine who to include in their experiments? Explain how to create a simple random sample using a number generator such as the one offered on Random.org.

8. Give students time to plan how they will record their data for each subject. For example:

9. Once teams determine the subjects they will test, they have to think about how they will gather the infor-

Subject ID	Selection from Q1	Selection from Q2	Selection from Q3

   mation from their subjects. Can your class pair up with another class for a short time to collect data?

10. As time allows, you might want students to script what they will say to each person who is willing to participate. [*"I'm doing a science experiment, and I'd love it if you would participate. I'm going to show you an image and ask you a question. Is that OK?" Show the first image, then show the next set of choices and ask, "which is the same?"*]

11. Give teams time to set up their data table, determine who will administer the group's test, and how the team will collect the data (work as a group or split up to test more people at the same time).

12. Once students have collected their data, it's time to analyze it. On a very simple level, they may be able to determine the percent of respondents who answer the questions correctly, or students should do statistical analyses most appropriate to their test. Unless time and class level permit long-hand calculations, students should use a free online statistical calculators, such as this one from GraphPad Software. You may also download the free Past software designed for scientific data analysis.

13. Give students the opportunity to share and compare their findings.

December 10, 2016
Animal Math

Design your experiment: How good is your numerical acuity?

Directions: Answer question No. 1 after your teacher's mini-experiment. Use this mini-experiment and the questions below to design your own experiment to study the strength of students' sense of quantities. Your teacher will define the timetable for the design process, experimental testing and data analysis.

Plan your experiment:

1. Watch your teacher do a simple experiment. Analyze what you see:

    a. What is being tested?

    b. How was the test set up?

    c. What are the strengths of the experimental design?

    d. What are some weaknesses of the design? Are there any confounding variables?

    e. Do you think the order of the images presented in the set would make a difference in the results?

2. Form a design group. Who's in your group:

3. What discrete quantitative sense do you want to test? Use clues from the article "Animal math" to generate ideas (refer to Page 23 for the example in the figure labeled "Reckoning with Weber's law"). Would you like to compare the sense of quantities of different categories of people (such as different age groups, math levels or genders) or would you like to study the ability of one group of individuals?

4. Create the visuals you will need to test your mathematical idea based on the example your teacher provided. State your hypothesis based on your idea. Determine the exact testing procedure you will use for each test subject and write this down. Who is administering the test? What script will the test administrator use? Think about minimizing confounding variables.

5. How many subjects will you test? You can use a sample size calculator to help you determine the number of people you should test based on the population of people you are able to test (as defined by your teacher).

6. Once a sample size is selected, how will you determine which subjects to include in your experiment? Use a random number generator such as the one offered on Random.org to create a simple random sample.

7. How will you record your data for each subject? Create a data table.

Implement:
8. Collect your data in the time allotted. Make sure you stick strictly to your procedural protocol.

Analyze your data:

9. What do you want to know about the data you collected?

10. Check with your teacher to determine how to analyze your data. If you're using a particular statistical test, your teacher will provide the online resource necessary to perform your analysis.

11. Summarize your results here. Do your findings support your hypothesis with statistical significance? Explain.

12. What errors do you think existed in your experiment? How could you modify your experiment in the future to remove those potential errors? What other questions might you want to test in the future?

13. Share and compare your findings with other groups. If the test that you developed used similar variables as another group, did you have similar results? If not, discuss why.